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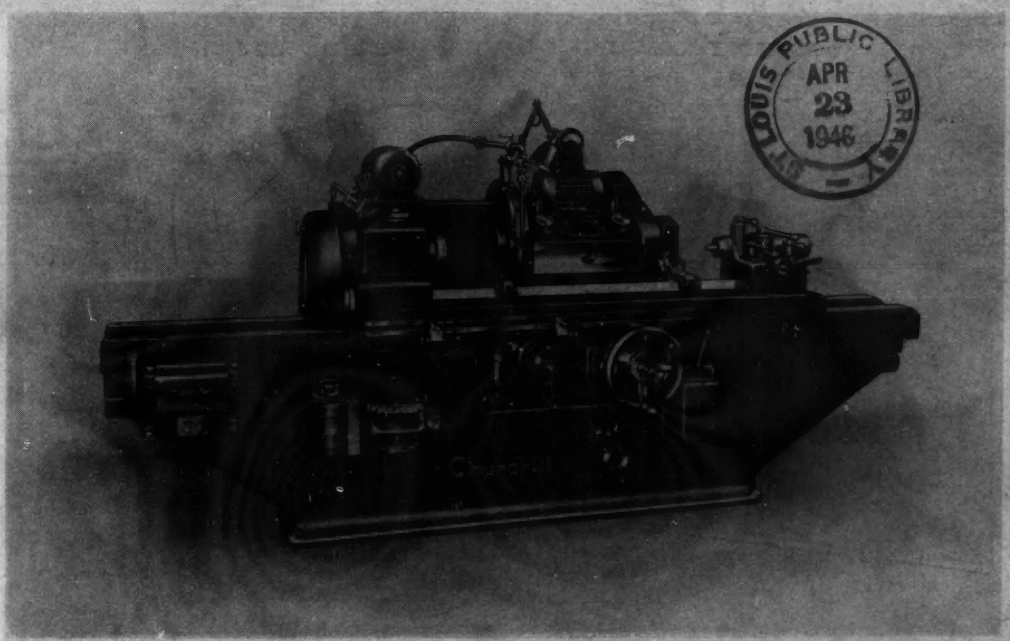

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AMERICAN ENGINEERING AND TECHNOLOGICAL ADVANCES DURING WAR-TIME.

THE accomplishments of American engineers which had such decisive influence on bringing World War II to a victorious end, have received little attention in the editorial columns of THE ENGINEERS' DIGEST *during the past five years. The paper shortage has compelled us to devote our regrettably few editorial pages to reporting almost exclusively on technical developments which have taken place in enemy and neutral countries, and on which practically no information could otherwise reach our readers in Great Britain and all over the British Empire.*

The splendid cooperation between the American Office of Scientific Research and Development and the British authorities, and between a large number of American and British engineering firms engaged in the development and production of materials and weapons of war, has covered the most urgent and vital common interests of both countries. A certain amount of information on American developments has reached the British industry, also through various British trade papers in the form of reprints from the American trade papers to which some British firms and libraries subscribe.

The interest of British engineers in obtaining, in concise form, exhaustive information on the work and achievements of their fellow engineers in the United States, has been obvious but has not yet been satisfied. In devoting the January and February, 1946, issues of THE ENGINEERS' DIGEST *to articles on important American engineering developments, we are attempting to meet this interest. In doing so, we are fully aware of the limitations imposed upon us by the very little space of mere fifty-two pages allocated for editorial contents of these special issues. The magnificent accomplishments of the greatest industrial country of the world, would require and deserve editorial treatment of hundreds of pages for each of the subjects covered in our survey. Therefore some of our articles have to deal with a narrow field of a broader subject, while others include numerous references to further sources of literature. Articles which for lack of space cannot be published in the two special issues on American war-time engineering developments, will appear as a special section in later issues of our journal.*

Under the chairmanship of Dr. Alexander Klemin, of New York University, the internationally known aeronautical expert and writer, prominent engineers of highest reputation cooperate in deciding on the editorial policy of the American edition of THE ENGINEERS' DIGEST. *The names of these fine representatives of American engineering are listed on the inside cover page of this issue.*

We are proud and happy that these distinguished representatives of American technical knowledge have joined the Editorial Advisory Board of our journal. Their active cooperation has been of invaluable help in compiling our special issues on American developments. It also shows the gratifying interest of American engineers in the interchange of international technological information as well as in promoting the feelings of friendship and appreciation between American and British engineers.

A further aim of THE ENGINEERS' DIGEST *has been to counteract narrow specialization and to promote the broadening of engineering knowledge. In a recent book by twelve prominent members of the Harvard faculty, appointed by President Conant and headed by Dean Paul H. Buck, drastic changes are recommended in the curriculum of Harvard and in the whole American educational system. The book, the result of the work of two years and many distinguished minds, recommends a balanced programme. It grants the inevitability of specialization in a technological society such as ours, but deprecates the present tendency in both high schools and colleges toward narrow specialism. It is great satisfaction to receive such high confirmation that we have been working in the right direction.*

J. E. PAJZS.

New York, December, 1945.

AMERICAN DEVELOPMENTS IN AIR CONDITIONING AND REFRIGERATION DURING THE WAR PERIOD.

By Dr. WILLIS H. CARRIER, Chairman of the Board, Carrier Corporation, Syracuse, New York.

THE exigencies of the world war have profoundly affected developments in nearly all branches of the arts and sciences. Although they brought many peacetime developments completely to a standstill, preponderantly, they have greatly accelerated developments in many fields. Both of these effects have been in evidence in the two closely allied arts of air conditioning and refrigeration. It is not always possible to distinguish between developments that have been delayed in application, but gradually brought to a successful conclusion during the war and those that have been wholly suggested by war uses, which are sometimes alien to their ultimate peacetime application. Following are a summary and brief description of outstanding developments in the air conditioning and refrigeration fields during this period.

A. Air Conditioning and Refrigeration Equipment.

1. A new type of air filter, combining filtration with electrostatic precipitation of dust.
2. A practical adsorption filter, suitable for use in ventilation.
3. Air conditioning cabinet or unit for individual room control in multi-room buildings. (See B-4).
4. A new type of thermostatic control, suitable for controlling the flow of heating or cooling medium alternately passing through the same valve. (See B-4).
5. New design for piping of high velocity air distribution in air conditioning. (See B-4).
6. A direct expansion heat transfer unit for cooling and dehumidifying air at extremely low temperatures. (See B-5).
7. A new development of centrifugal compressors for refrigeration for low temperatures. (See B-5).
8. An air conditioning unit employing an absorption system of refrigeration with water as the refrigerant.
9. Development for refrigeration in air conditioning of multi-cylinder high speed reciprocating compressors with variable capacity control.
10. "Lo-Fin" tubing.
11. Portable self-contained low temperature air cooling units for cold storage.

B. Air Conditioning and Refrigeration Applications.

1. Application of air conditioning with refrigeration to windowless factories processing non-hygroscopic materials.
2. Addition of refrigeration to the air conditioning of cotton mills.
3. Dehumidification and humidity control for blast furnaces.
4. A new system of air conditioning for multi-room buildings and passenger ship staterooms.
5. Dehumidifying and cooling the air in a barometric wind tunnel for aeroplane engine testing.

A-1. Electrostatic Air Filters.

The demands for dust-free air in precision industries making war products have speeded up developments in air cleaning equipment. Notable among these are electrostatic filters. Utilizing the principle of electric precipitation long used for reclaiming valuable dusts from air, the electrostatic filters have been developed for use in air conditioning systems, and provide a degree of cleanliness not achieved with other types of cleaning devices.

Airborne dusts on entering the electrostatic filter pass through an ionizer where they receive a positive electric charge. They then pass through an electric field composed of a series of positively charged and grounded plates. The repellent force of the positively charged plates and attraction of the earthed plates on the positively charged particles cause precipitation of the dust.

War developments have brought improvements in the electrostatic filters. One design employs an endless conveyor which slowly moves the earthed plates between stationary positively charged plates. The greater portion of the dust is deposited on the earthed plates which pass through a viscous bath at the bottom of the conveyor where the dust is removed automatically in a continuous cleaning process, and the plates are recoated with viscous material. The smaller portion of the dusts which collects on the positively charged stationary plates is removed mechanically by wipers attached to the moving chain. This type of electrostatic filter is especially suited to the handling of large air volumes.

A more recent development combines the electrostatic principle with mechanical filtration to obtain the high efficiency of electric precipitation with the ease of the "throw-away" type of mechanical filters. In this unique design, which is especially advantageous for the smaller capacities, the ionized air is passed through an Airmat filter in an electrostatic field formed by charged wires and an earthed grid.

*(1) Electrostatic Air Cleaning as Applied to Air Conditioning, by J. R. McConnell, *Heating & Ventilating*, August, 1940.

(2) Electrostatic Air Cleaning in Heating, Ventilating and Air Conditioning, by C. M. Sanders, Jr., *Industrial Power*, August, 1942.

(3) Electrical Precipitation, author not given, *Mechanical World*, September, 1944.

A-2. Adsorption Filters.

Adsorption filters, for removing vapours and gases from air, are now applied in air-conditioning installations. Used in series with dust removal filters, they provide freedom from contamination that permits recirculation of large volumes of air, thereby effecting great savings in air-conditioning costs. A widely used adsorption filter for air recovery now utilizes a specially impregnated granular activated carbon which is effective in attracting and holding the many varieties of gases that may be present in air in small quantities.

(1) Removing Odors with Activated Carbon, *Sheet Metal Worker Magazine*, September, 1938.

(2) Eliminating Objectional Odors in a Large Air Conditioning Installation, by D. Mortara and Jules E. Brunner, *National Engineer*, July, 1938.

(3) Air Conservation Engineering, published by W. B. Connor Engineering Corp., 1944.

A-8. Absorption Refrigeration in an Air Conditioning Unit.

An absorption refrigerating machine using water as the refrigerant has been developed for residence air conditioning, and has been incorporated in a self-contained year-round air conditioning unit. Steam used for boiling the refrigerant out of the absorbent, lithium bromide, and for heating during winter operation is generated within the unit by a gas burning boiler.

The principal parts of the refrigerating machine are: refrigeration generator, condenser, evaporator, absorber and liquid heat exchanger. There are no moving parts within the refrigerating cycle and the entire cycle is under a vacuum at all times. Pressure within the generator and condenser is approximately

* References to American publications mainly.

1 lb. per sq. in. absolute, and approximately 0·15 lb. per sq. in. within the evaporator and absorber.

(1) An All-Year Gas Air Conditioning Unit, by H. C. Pierce, *Mechanical Engineering*, March, 1945.

(2) Heat Operated Absorption Units, by Dr. R. S. Taylor, *Refrigerating Engineering*, March, 1945.

(3) Absorption Regrigeration Used for Air Conditioning, by W. F. Friend, *Heating, Piping & Air Conditioning*, September, 1940.

(4) Recent Developments in Absorption Refrigeration, by G. Miller, *Heating, Piping & Air Conditioning*, October, 1941.

A-9. Reciprocating Compressor Developments.

Prior to the war some manufacturers offered high speed compressors operating at speeds up to 1750 r.p.m. These machines were equipped with variable capacity control to permit direct drive, and, at the same time, matching of evaporator loads.

During the war further improvements have been made in compressor design for high speed operation. The most important of these improvements are :—

(*a*) Refinement in design of variable capacity control to extend its usefulness to all types of application. The most common methods for obtaining capacity variations are by means of holding the suction valve open or by-pass from one cylinder to another or between pairs of cylinders. The trend is towards the first-named method, since by sequence opening of suction valves in the individual cylinders precise matching of compressor and evaporator loads results.

(*b*) Improvement in compressor capacity and efficiency through the reduction of valve losses by experimentally determining the best proportions and shapes for valve ports and valves. A unique feature in this research was the application of the wind tunnel method of testing to stationary models and the relating of these results to the corresponding losses in compressors in operation.

(*c*) The successful development of methods and devices for overcoming the tendency to increased noise and vibration at higher speeds.

(*d*) Making all compressor parts subject to wear replaceable and interchangeable as, for example, cylinder liners, precision insert bearings, etc.

(1) Variable Capacity Radial Compressors, Parts I. and II., by C. R. Neeson, *Refrigerating Engineering*, February, 1942, March, 1942.

(2) Progress in Refrigerant Compressor Test as an Aid to Design, Part II., by Lars Hanson, *Refrigerating Engineer*, July, 1945.

A-10. "Lo-Fin" Tubing.

The last six years have seen the introduction and general adoption of "Lo-Fin" tubing for condensers and evaporators for use with the various "Freon" refrigerants. This tubing, usually of copper or copper alloy, has the external surface increased approximately three times by the extrusion of $\frac{1}{16}$ in. spiral fins of approximately $\frac{1}{8}$ in. pitch. The ends are belled so as to be the same diameter as the fins to permit installation and replacement of tubes in header sheets. This has resulted in reducing the number of tubes required to approximately one-half, thus reducing the size, cost and maintenance of both condensers and evaporators where refrigerants having low latent heats are employed.

Cooler and Condenser Heat Transfer with Low Pressure Freon Refrigerant, by Walter Jones, *Refrigerating Engineering*, June, 1941.

A-11. Self-Contained Refrigeration Units.

During the war, both the Army and Navy demanded a portable self-contained air cooling unit to be used in connection with portable cold storage warehouses. This led to a development which is highly adaptable to peacetime uses. This unit consists of a motor-driven compressor and an air or water cooled condenser comprising the "high side" which is located on the outside of an insulated panel. On the inside of this insulated panel is the "low side" comprising a direct expansion cooling coil constructed of finned tubing over which room air is circulated by means of a centrifugal fan driven by a separate motor or by the compressor motor through a shaft extending through the panel. Provision is made for water defrosting. The unit, which is entirely self-contained, is completely evacuated, dehydrated and charged with refrigerant at the factory which permits it to be ready for immediate service upon installation. The standard units employed by the Navy and Army were 3 h.p. and $7\frac{1}{2}$ h.p. respectively. Other sizes are now in development for post-war applications. This unit, complete with controls, will maintain automatically any desired temperature within storage space from —10 deg. F. to + 40 deg. F., and is adapted to assembly line production. This unit should be most advantageous to the smaller users of refrigeration for storage purposes since it permits complete factory assembly and testing, resulting in a low cost installation.

Portable Refrigerators for the Armed Forces, by M. E. Mooney, *Refrigerating Engineering*, March, 1943.

B-1. Air Conditioning in the Machine Shop.

The employment of large windowless factories during the war for the production of aeroplane engines and aeroplane accessories necessitated air conditioning with cooling by refrigeration. The air conditioning units were usually dispersed at convenient locations throughout the factory, and often conveniently located in roof trusses. Generally, cold water was supplied to these units from a central cooling plant employing large units of centrifugal refrigeration. Unexpected advantages of this application were discovered. It permitted greater precision in delicate machining operations and increased output due to higher efficiency of workers. It also greatly reduced fatigue of workers heretofore occasioned by high temperatures and humidities under summer conditions. This reduction of fatigue not only increased the efficiency of the workmen, enabling them to produce a greater output, but reduced shop errors and accidents. The cost of heating in winter was sometimes sufficiently reduced to pay for the power required to operate the air conditioning system. The cost of plant operation and maintenance for windowless buildings having an air conditioning system was found to be lower than for the conventional factory having windows and the conventional heating system. It is believed that this wartime experience will lead many of the larger manufacturers to install air conditioning in plants not requiring air conditioning for the processing of the product.

Report from Industry : Should Factories Be Air Conditioned ? by R. D. Tutt, W. E. Goohs and F. G. Tykle, *Heating, Piping and Air Conditioning*, January, 1945.

B-2. Application of Refrigeration to Air Conditioning for Cotton Mills.

Cotton spinning mills develop a great amount of heat, and also require high humidities both for quality and quantity of production. These requirements often cause atmospheric conditions in the mill to become almost intolerable for the worker. It has long been recognized that some form of cooling would be greatly advantageous from the standpoint of both the worker and the mill owner, as it would undoubtedly result in better efficiency and permit employment and retaining of a higher class of labour. While the desirability of such cooling is appreciated, it was formerly thought that the cost and maintenance of such equipment would be prohibitive. However, with improvements made in water cooling through the advent of large centrifugal units, which may be either motor or turbine driven, the cost of both operation and maintenance has been so reduced that the cost of installation, operation and maintenance have been brought within the realm of

practicability. This has been evidenced by post-war plans for several such plants.

Atmospheric Conditions in Cotton Textile Plants, Spec. Bull, No. 18 of the U.S. Dept. of Labor Division of Labor Standards.

B-3. Air Conditioning for Blast Furnaces Made Practicable.

During the war, there was demand for the maximum production from all available blast furnaces. It was found that production could be increased by the reduction of the moisture content in the air supplied to blast furnaces together with a uniform control which stabilized the "burden," that is, maintained the ratio of ore to coke constant. Another important advantage discovered was that with a uniform moisture content in the blast, it is possible, by regulating the "burden," to control the analysis of the iron, particularly with reference to silicon. This makes it practicable to produce iron uniformly to specification. Many years ago, this process was tried but it was only with the advent of improvements in refrigeration, particularly the centrifugal refrigerating machine and the spray dehumidifier, that it has become practicable.

(1) Moisture Removal from Blast Furnace Air, by L. L. Lewis, *Refrigerating Engineering*, November, 1939.

(2) Air Conditioning Benefits Blast Furnace Operation, by E. K. Miller, *Steel*, November, 1941.

(3) Dry Blast and Production for War, R. VD. Dunne, *Refrigerating Engineering*, July, 1942.

(4) Economic Aspects of Pre-Compression Refrigerated Dry Blast, by R. VD. Dunne, *Iron and Steel Engineer*, July, 1942.

B-4. Multi-Room Air Conditioning.

A self-contained cabinet or unit (A-3) has been developed to provide ventilation, air distribution and humidity control combined with individual temperature control by heating or cooling. It is particularly adapted to tall multi-room buildings and to air conditioning in passenger ships. Primary air in sufficient volume for ventilation purposes is supplied to the unit from a central station air conditioning system (at relatively high pressure). This air, discharged at high velocity in the unit, induces several times its volume of room air through a plate fin coil. The air thus induced is either cooled or heated by water from a central station. In the unit, there is embodied a new type of thermostatic control (A-4) capable of governing the flow of either the hot or cold water so as to maintain any room temperature which the individual occupant desires. This unit has no moving parts and occupies about the same space as the ordinary steam or hot water radiator. It may be concealed under the window sill or enclosed in a separate cabinet outside.

The units are usually dispersed in the same manner as ordinary radiators, one under each window, to counteract cold air currents in winter and to permit any subdivisions of the space by partitions. The humidity and ventilation is controlled by admission of a constant quantity of highly conditioned air. Normally, no moisture is added or removed in the unit. Its primary function is to heat or cool the room to a desired temperature which may be independent of the temperature in other parts of the building. The primary air to each individual unit is supplied through a standard 3-in. diameter connection. This connection is of flexible metal hose for ease of installation, and to provide for expansion and contraction. The air passing through these flexible connections to the units is fed from round vertical risers, employing high air velocities, located in pilasters between the windows and constructed of spirally seamed pipe (A-5) formed from a single strip of metal. They are air-tight under pressure, and in standard sizes varying from 4 in. to 8 in. in diameter. They are provided with special standardized fittings which insure air-tight connections. These units and their associated equipment are employed in the system (B-4) which, it is believed, marks a distinct advance in the art of air conditioning.

W. S. Bodinus, *Refrigerating Engineering*, April, 1944.

B-5. Air Conditioning of the Barometric Wind Tunnel.

Early in the war, a National Advisory Committee for Aeronautics was established and large appropriations were made for research and testing. The largest single project was a barometric wind tunnel for aeroplane engine testing, which was located at Cleveland, Ohio. This tunnel is capable of testing aeroplane engines with standard propellers at any plane speed up to 500 miles per hour and any capacity up to 3000 h.p. It is a closed system handling a maximum of 10,500,000 cu. ft. of air per minute at barometric pressures ranging from one atmosphere to less than one-fourth of an atmosphere. This required a maximum removal of heat, under extreme conditions, corresponding to approximately 7000 tons of refrigeration and air temperatures in the throat of the tunnel ranging from 50 deg. F. above zero to —67 deg. F. It was also necessary to supply large volumes of outside air, properly cooled and dehumidified to tunnel conditions, in sufficient quantities to provide a dilution of the exhaust gases so as not to affect the engine performance.

To cool the vast quantity of air circulated within the tunnel to suit all the conditions of engine testing required a capacity and a flexibility in performance beyond the bounds of any previous engineering experience. Specifically, it led to the development of a new type of direct expansion air cooling coil (A-6) and of a centrifugal compressor (A-7) for Freon-12 (Dichlorodifluoromethane) capable of producing ratios of compression higher and more variable than ever before attempted.

The air cooler consists of approximately 250 encased units 12 ft. × 3 ft. × 6 ins. deep. These are arranged in banks having inclined sawtooth formation at the maximum section of the tunnel which is 51 ft. in diameter. By this arrangement, a total face area of the coils was obtained, nearly four times the cross-sectional area of the tunnel, and the velocity of flow through the coils is reduced to a practicable figure.

The coils (A-6) are of plate fin construction, each having 48 direct expansion refrigerant circuits employing $\frac{1}{2}$ in. "hairpin" tubes brazed into a divided steel header. These headers connect into 12 in. gas and 4 in. liquid branch mains. They are designed to handle a quantity of liquid refrigerant considerably in excess of that required for cooling. Spiral restrictions at the entrance to each circuit provide uniform distribution to each of the circuits. Each header is likewise provided with orifice restriction effecting the uniform distribution of refrigerant to each of the headers in a particular longitudinal row. The distribution to the horizontal rows at each elevation is controlled by differential pressure valves which compensate automatically for the large variations in liquid head to give the desired uniform static pressure at each horizontal liquid header under variable flow conditions. The 12 in. gas and the 4 in. liquid branch mains are respectively collected into four 32 in. gas and two 8 in. liquid mains. The liquid refrigerant is pumped from a receiver to the coils through the 8 in. liquid mains and the gas, together with the excess liquid, is returned through the 32 in. mains to the receiver. A unique feature of this installation is the provision made for the flexibility in the 32 in. gas suction lines which are subjected to a 2 in. lateral movement caused by the expansion and contraction of the long wind tunnel with temperature change.

The receiver pressure is automatically controlled to give any desired coil temperature in the range between 67 deg. below zero and 35 deg. above zero. This

control is effected through six automatic dampers acting as back pressure valves capable of controlling the pressure in the receiver and cooling coils over the range of 5 lbs. to 40 lbs. absolute. These valves, which have a combined capacity of over 84,000 cu. ft. of "Freon" gas per minute discharge into a 30 in. header serving fourteen "Freon" centrifugal compressors. These compressors are of special four-stage construction, designed to work economically in the range from a maximum ratio of compression of 29 down to a minimum ratio of compression of 12. Each compressor is driven by a 1500 h.p. motor and discharges into an individual condenser. The liquid refrigerant from each condenser is expanded back into the main receiver in three stages by means of three balanced float valves with two intermediate receivers. At the first and second intermediate expansion stages, the flash gas is bled off to the inlets of the third and second stages, respectively, of the compressor. With this unusually wide range of compression and with a low latent heat refrigerant such as "Freon-12," flash gas constitutes a large percentage of the total volume handled and, therefore, this intermediate expansion of the liquid greatly increases the refrigeration capacity of the compressor as well as the efficiency of the refrigerant cycle. This compressor, with its associated refrigerant cycle, offers a simple and highly efficient means of low temperature refrigeration for post-war applications.

Low Temperature Refrigeration System, by M. J. Wilson, *Refrigerating Engineering*, November, 1944.

BERYLLIUM COPPER ACCOMPLISHMENTS.

By R. W. CARSON, Vice-President, Instrument Specialties Company, Inc., Little Falls, N.J.

WITH the development of specialized facilities for fabricating beryllium copper, the unusual combination of desirable spring properties in this alloy has given it an important place in the design of a wide range of products. Brief data on physical properties and some typical examples of its use may therefore be of interest.

Because it has an entirely new and highly desirable combination of spring properties, beryllium copper has made possible a new field of spring accomplishments. Of all corrosion resisting spring alloys, beryllium copper offers the highest strength, electrical conductivity, wear resistance, and endurance strength. In addition, it is non-magnetic, withstands higher service temperatures than bronze, and when properly heat-treated has less drift or tendency to set under prolonged loading than any other spring material. Under corrosion fatigue conditions beryllium copper has the highest strength of any spring material and safely withstands extreme cold.

And then its most significant advantage—the ability to take forming in a relatively soft condition and then be hardened in heat-treating fixtures with the result that beryllium copper springs can be made to far closer tolerances than obtainable with any other spring alloy. With all these advantages it is no wonder that beryllium copper has been so widely used in war equipment—and offers such promise for improving the performance of everyday products.

There is a price to be paid for these advantages, of course. More care and control is required in mill production of beryllium copper than for ordinary spring materials. Because all of these properties derive from solubility and dispersion of only two per cent. of beryllium added to copper, it is a sensitive alloy. Each mill lot must be tested for hardening response and heat-treated at the one best time and temperature for best properties. Nor will a single heat-treatment for a given lot bring all properties to a simultaneous peak, so some skill and experience is helpful in determining just what hardening procedure will bring out the best combination of properties needed for a specific application. Although successful use of beryllium copper demands its price in greater care and specialized experience, it is no different from many other modern metallurgical specialities. To capitalize on the inherent advantages of beryllium copper it has been necessary to develop new and in some instances unconventional methods of fabrication.

Ordinary coiling machines for example, have serious limitations in handling beryllium copper, because of distortion occurring in bulk hardening of coiled springs. One of the outstanding advantages of beryllium copper over all other spring alloys is that springs can be fully stress relieved while undergoing hardening, but the very act of stress relief in the absence of any holding or restraining force causes distortion. Obviously, beryllium copper coil springs should be supported during hardening. To accomplish this at low cost, special coiling machines were developed by Instrument Specialists that wind springs on a steel mandrel on which the springs remain during the hardening operation. This procedure not only delivers springs that are straight and uniform, but also to far closer tolerances on load test than possible with ordinary springs.

In fabricating flat springs or punch press parts from beryllium copper the problem of distortion during heat-treatment is readily met by the use of steel clamps or fixtures designed to hold important dimensions during hardening. Such fixtures will readily correct small inaccuracies in tooling or variations in spring back, thus giving closer final tolerances than obtainable with ordinary spring materials.

"Microprocessing" is the term applied by Instrument Specialists for the combination of heat-treat forming and heat-treatment of each lot to peak obtainable properties.

Because of these advantages of microprocessing, beryllium copper has been used in a wide range of

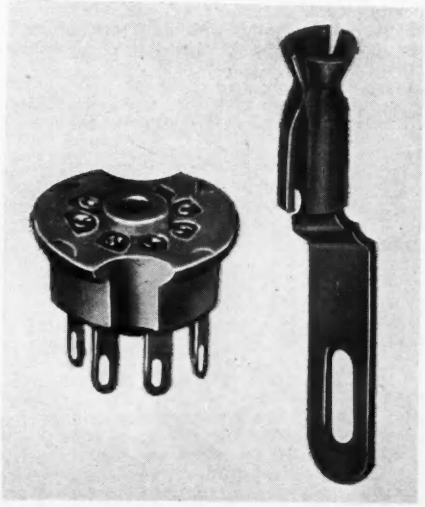

Fig. 1. **Eby Miniature Radio Tube Socket with "microprocessed" beryllium copper contact.** (Soldering tab is soft and ductile; contact end is fully hardened and maintains a pull-out tension of 8 oz. to 16 oz.)

(a) Beryllium copper contact 4½ times actual size.
(b) Socket with 7 beryllium copper contacts 1½ times actual size.

TABLE 1.
Where beryllium copper is being used to-day.

Contol relays	Sewing machines	Electrical instruments
Chronometers	Dynamotors	Fire extinguishers
Pressure regulators	Tool grinders	Radar contacts
Water purefiers	Kitchen mixers	Tachometers
Aircraft carburettors	Airplane propellers	Telephone dials
Push button switches	Calculating machines	Free wheeling clutches
Adding machines	Aircraft instruments	Gun directors
Solenoid cores	Radio tube sockets	Tape transmitters
Water pump valves	Fuel pumps	Timers
Oxygen regulators	Fuse holders	Telephone relays
Snap switches	Crystal sockets	Motor controllers
Circuit breakers	Radio headsets	Loud speakers
Lighting controls	Dial Gauges	Thrust washers
Band instruments	Radio trimmers	Flexible couplings
Automobile clocks	Automatic pilots	Rheostats
Vacuum cleaners	Hearing aids	Battery clips
Portable drills	Pin jacks	Speed governors
Hair dryers	Voltage regulators	

applications some of which are listed in Table 1. But a detailed discussion of a few typical uses will show what can be done.

New radio tubes of miniature size required a tube socket that would hold each pin in an 8 oz. grip—a grip that would not relax under repeated insertions, under wide temperature range or with the passage of time. This was beyond the strength of any other conducting spring alloy, but beryllium copper did the job with pressure to spare. In fact, the new contact shown in Fig. 1 can be made to hold a 1 lb. pull-out load per pin.

One of the problems faced with the beryllium copper contacts was the high hardness and low elongation in the tabs, whereas they should be soft for ease in bending in attaching leads. So a special heat-treating procedure, selective hardening, was developed which resulted in the contact end being heat-treated for maximum strength, with the tab dead soft. Millions of these parts have gone into tube sockets made by H. H. Eby Co. for Signal Corps and Navy equipment.

Electrical equipment on aeroplanes has taken over many control and operating functions with small high-duty motors doing the work. To do their work these motors required brush springs that stand high operating temperatures and maintain brush pressure with minimum loss of brush tension with brush wear. Beryllium copper gave these springs the stamina to withstand operating temperatures 100 deg. F. higher than bronze could take, at working stresses enough higher to result in appreciable savings in weight and space, and produced to sufficiently close tolerances to eliminate the need for excessive clearance between spring and spring holder.

But the most significant advantage obtained with properly hardened beryllium copper was the reduction in pressure loss with brush wear possible when each lot of wire was heat-treated for maximum strength and minimum drift (Fig. 2). A detailed discussion of this important advantage is included in the article, "How to Design Brush Springs for Long Brush Life," listed in the references at the end of this article.

Many applications for beryllium copper take advantage of its good drawing properties. But in the drawn cup shown in Fig. 3 it was also desired to have spring elements formed in the side wall of the drawn cup. The part, incorporated in a variable density filter, is snapped over binocular eye pieces. Too heavy tension gave too much wear and made ready removal difficult; tension too light allowed the filter to fall off.

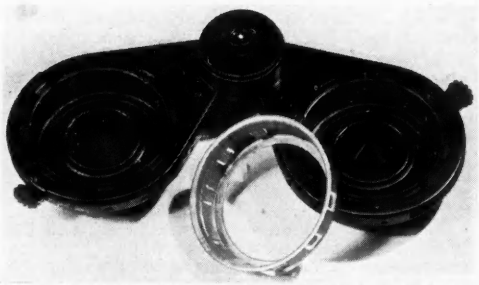

Fig. 3. **Beck Lee binocular filter designed around two beryllium copper drawn cups with springs formed in the side walls.** The part is drawn without intermediate anneal, and each spring finger is held in desired position by heat-treat forming fixtures.

The right tension was held within a narrow range by heat-treating the rings on simple fixtures that held the separate spring elements in the proper position during hardening. In addition, the fixtures held the cup flat and true. By using specially annealed strip no intermediate anneals were necessary in drawing the cup.

Heat-treat forming also solved a problem of long standing in contact blades for relays where contact

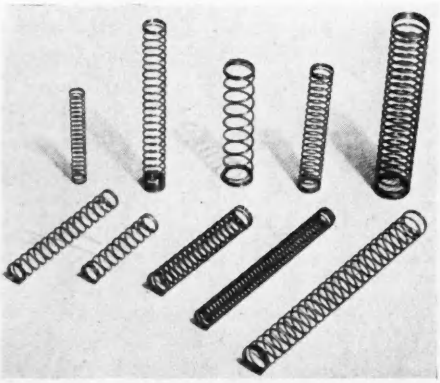

Fig. 2. **"Micro-processed" beryllium copper brush spring** designed to double the service life of carbon brushes for small motors. These springs will safely stand temperatures 100 deg. F. higher than bronze or steel, a requirement for motors using new high temperature insulating materials.

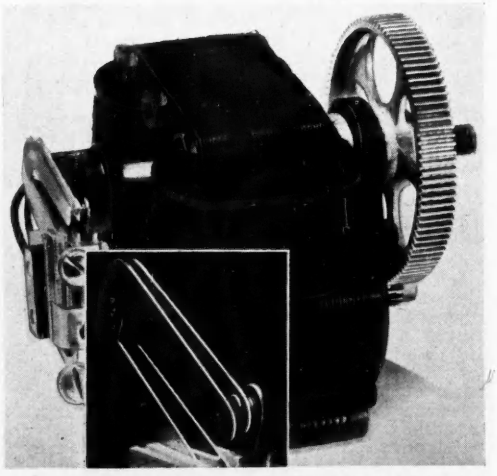

Fig. 4. **Hand signal generator made by Holtzer-Cabot.** using pre-formed beryllium copper contact blades so precisely formed that no hand adjusting is needed to obtain the required contact pressure.

spacing or contact pressure must be held to close tolerances. The traditional approach to this problem was to assemble flat blades and bend each one by hand, overbending to allow for springback and subsequent relaxation. For the Holtzer-Cabot field generator illustrated in Fig. 4, beryllium copper blades made with the proper angle of bend eliminated these hand adjusting operations and saved several times the cost of these superior springs.

Angle of bend was held in a fixture during the hardening operation using a high-temperature, short-time heat-treatment. Complete stress relief accomplished concurrently with hardening resulted in springs far more stable and resistant to change in service than possible with any other alloy.

Beryllium copper is usually associated with spring applications, but its unusual combination of wear resistance and non-magnetic properties makes it the ideal material for solenoid guides. No other non-magnetic material even closely approaches beryllium copper for wear resistance. In the design developed for Yale & Towne, Fig. 5, the beryllium copper guide

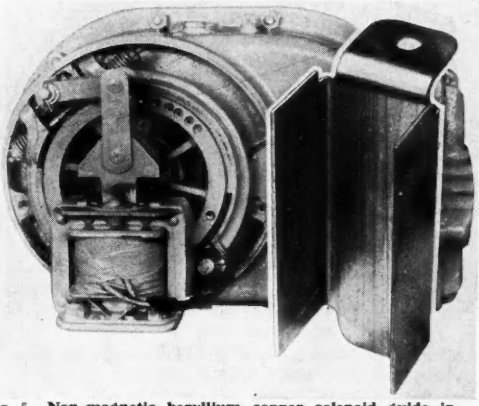

Fig. 5. **Non-magnetic beryllium copper solenoid guide in the Yale and Towne electric hoist outlasting other materials by more than 10 to 1.**

outlasted the next best material by 10 times.

In addition to exceptionally long life, the beryllium copper guide also answered another important design problem. Heat-treat forming produced parts of closer tolerances which permitted reducing the clearance between the solenoid and guide, thus giving more accurate alignment and less wear.

As mentioned earlier, one of the important advantages of beryllium copper is that it can be heat-treated so as to bring to a maximum those specific properties needed for a particular part. Table 2 indicates attainable properties as compared with other spring materials, when lots of good quality beryllium copper are heat-treated to bring the desired property to a maximum. Such processing requires a hardening test on each lot of material and a heat-treatment selected for the property to be brought to a maximum.

TABLE 2.

Material	Elastic Modulus	Tensile Strength	Design Stress	Conductivity per cent.	Operating Temp. Max.·	Relative Drift*
					deg. F.	
Spring Steel	30	300,000	90,000	8	250	·15
Stainless Steel	28	200,000	75,000	4	300	·15
Beryllium Copper	19	190,000	70,000	28	300	·05
Phosphor Bronze	15	98,000	50,000	15	200	·12
Spring Brass	14	75,000	30,000	25	175	·20

* Drift is the change in position under a given load and time expressed as per cent. of load deflection.

In general, the low modulus of beryllium copper is desirable for spring applications to minimize variations in force with variation in deflection; high tensile strength permits designing for minimum space or weight. Under conditions causing corrosion in steel, beryllium copper has the highest working strength available. When good electrical and heat conductivity is required, beryllium copper has the best combination of strength and conductivity. Low drift properties plus high safe operating temperatures of beryllium copper assure maintenance of spring pressure during the full life of the part.

REFERENCES.

For additional technical information to guide in applying beryllium copper to specific jobs, the following articles are suggested for study.

"Bibliography of Beryllium Copper," published by Instrument Specialties Co.

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"Tailor Made Springs for Beryllium," *Modern Industry*, November 15, 1942, pages 36-37.

"Quality Inspection of Beryllium Copper," by Wayne Martin, *Metals & Alloys*, June, 1943, pages 1203-1207.

"Predicting Spring Performance of Beryllium Copper Wire and Strip," by H. G. Williams, *Iron Age*, July 8, 1943, pages 62-67.

"Making Beryllium Copper Behave, by R. W. Carson, *Metals & Alloys*, December, 1943,

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RECENT PROGRESS AND THE FUTURE OF INDUSTRIAL RADIOLOGY.

By HERBERT R. ISENBURGER, President, St. John X-Ray Service, Inc., Long Island City, N.Y.

WHEN reporting on recent progress in the field of Industrial Radiology, one must bear in mind two things: (1) very little, if any, research was conducted during the war period which could lead to improvements in generating equipment; and (2) all advances which were made have been to further the war effort. Just which advances and how they can be applied to peace-time inspection work remains to be seen.

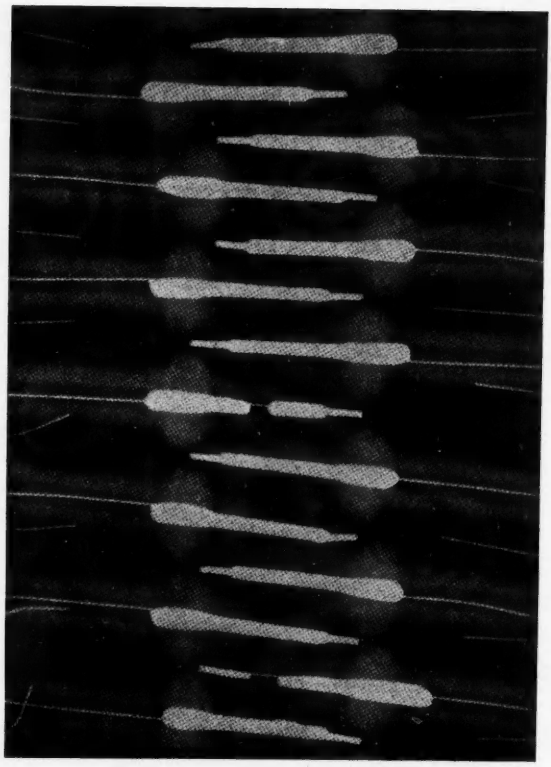
At the time of the closing of our manuscript for the Second Edition of *Industrial Radiology* (Chapman & Hall, London; John Wiley & Sons, New York) in 1942, the use of million-volt x-ray machines was well established. Numerous applications have been described in the literature. One of the most useful applications is the mass-inspection of ammunition. A motorised ring carries the shells with the loaded cassettes into the exposure room and is placed underneath the unit. The latter is lowered and the tube centred to inspect 50 shells simultaneously. Every 18 minutes a new battery of shells is ready for examination (*Electronics*, December, 1944, p. 150).

An adaption to X-ray equipment of the photographic exposure meter is the photoelectric tube timer. It is based on the principles of electronic method of controlling the density of the resulting exographs (*Steel*, January, 1945, p. 98).

Although not yet advertised, single-pole X-ray tubes have been made in this country recently. They are known to Europeans for almost 10 years. The fact that we did not have this tube available throughout the war constitutes a serious neglect on the part of the responsible manufacturers. Just how many lives have been lost on account of unchecked defects in aeroplane engine cylinder heads will never be known. However, without the aid of an "oxtail tube," the base of these finned heads cannot be X-rayed satisfactorily. To-day these tubes are being used to improve the sharpness of the image on fluorescent screens. They also facilitate mass-fluoroscopic inspection.

Great advances have been and always will be made in improving techniques and in reducing the cost of inspection. One new tool has come to the fore which promises to be of great help in the study of foundry technique and control. This is X-ray micrography. Micro-radiographs provide a means to study micro-cavities. These together with an exograph of the entire casting enable the radiographer to interpret and to diagnose more accurately. This method should also prove to be of value in pilot casting examination (*Transactions, American Foundrymen's Association*, June, 1945, p. 1111).

The expense of radiographic inspection has been before the war, and undoubtedly will again be, the excuse for not employing this tool which assures sound material and perfect workmanship. While X-ray inspection is admittedly an added expense to the manufacture of a product; it is money well spent as a factor of insurance if for nothing else. In some cases the cost has been brought down to a negligible amount. As an example we quote the inspection of spark plug insulators. The actual cost during the first five years is ½ cent. per insulator and it will be less once the installation has been written off. The equipment consists of a two valve-tube rectified Villard-type circuit and an oil-immersed 120 kv. Eureka X-ray tube without target cooling. The entire equipment is placed underneath a work-bench in the production line. A lead-lined box is mounted over a suitable opening in the bench top through which the rays emerge. The insulators are mounted on trays, holding 200 each, and X-rayed on a 14 in. by 17 in. sheet of Defender X-ray paper. The use of paper in this case is even more satisfactory than film, because it not only reduces the contrast between the ceramic insulator and the metallic insert, but it also halves the processing time by permitting two exposed sheets to be placed in a single hanger back to back. The result is shown in the accompanying illustration which contains two defective insulators where the insert does not represent a solid mass. There remains no doubt that responsible manufacturers will continue this inspection, at least for certain types of aircraft plugs.



Not always has progress lead to rea improvements. A word of warning at this time may help to prevent grave mistakes. Many factories are now equipped with million-volt machines. It is true that by some manipulation, the back scatter from the tube target can be utilised. This furnishes about 400 kv. and with very large distances, 10 feet or more, reasonably good results may be obtained on objects which would ordinarily require an exposure at 100 kv. or even less. If these objects are magnesium or aluminium castings where small defects have to be detected, these can only be shown up with low voltage and longer exposure time. A well-equipped laboratory, therefore, should have available 100 kv. or 150 kv., 250 kv. and, if necessary, million-volt X-ray units, or a capsule of radium in place of the latter installation. To assure best results, the correct wave-length radiation is a basic requirement.

No doubt that many of the war-produced mass-inspection methods can fruitfully be applied to any similar inspection routine. Conveyor belt, rotating disk and other mounting devices facilitate handling and speed up the process. Automatic film processing will become a necessity for any well-organised mass-inspection job where either a large battery of X-ray machines is in continuous use or where short exposures in routine work require the handling of large quantities of film.

The end of the war production boom left hundreds of factories with X-ray installations. In a good many cases the operator received just enough training to be able to perform one or two routine jobs. Change to peace-time work requires the service of a man who is well-trained and able to tackle any job that may come along. With government specifications lifted, the manufacturer as well as the purchaser rely on the ability and integrity of the radiographer for the correct results and interpretation. It is in this field of training personnel where a great deal still remains to be done. Only with thorough knowledge of his tools and technique can the operator be expected to perform his responsible job. It takes years of experience to become an expert in this field.

However, with properly designed and installed X-ray equipment available and a well-trained man in charge, the X-ray laboratory will always be an asset to the progressive manufacturer. Future requirements, more than ever before, will call for quality products. Still higher temperature and higher pressure services

will demand absolutely sound castings and welds. Severly stressed parts in the aircraft industry, for instance, must be physically perfect and free from internal flaws. Important new fields may open themselves for X-ray inspection. Locomotive parts and other railroad equipment, bridge inspection, ship construction, chemical plant installations, and numerous other fields including that of applied atomic energy will provide fertile ground for this ever-increasingly important inspection tool.

SOME WARTIME LIGHTING DEVELOPMENTS.

By SAMUEL G. HIBBEN, Director of Applied Lighting Westinghouse Electric Corporation, Bloomfield, New Jersey.

IN the United States as well as in England and in every other country engaged in war, the available talent and materials for approximately the past six years have been concentrated upon items of immediate military importance. In the lighting field this has curtailed the engineering developments of new lighting fixtures to a measurable extent although not without some benefits, among which could be mentioned the extra attention to uses of fibre and plastic substitutes for aluminium and steel, the reduction of all unnecessary weith of metal in industrial and commercial luminaires, and some real progress towards simplification. Where copper for conductors has been scarce, the best engineering has been needed to select optimum voltages and most economical types of wiring circuits. Plated iron has been used instead of brass for lamp bases and ingenious metal alloys often relieved the shortages of nickel, tin, zinc or tungsten.

In the case of light sources or lamp bulbs, the war years have not worked any great detriment because the developments needed for military uses will, in the majority of cases, fit into subsequent peace-time applications. In fact, the demands of war have frequently incited a speeding up of lamp engineering. standardization, too, has been given a boost forward.

Attention to standardised volume production has, of course, been an important factor in America's ability to meet wartime requirements. What a colossal job this has been can be appreciated when noting that in 1944 approximately one thousand million electric lamps of all types were produced in the United States, of which some 775,000,000 were general service, large incandescent filament lamps, and about 35,000,000 were fluorescent tubular lamps. This production was chiefly for domestic consumption, but a fair percentage went to military allies or overseas' operations.

Research and engineering on fluorescent lamps, and to a more modest extent on mercury vapour lamps, in the United States continue surprisingly well, and all important demands primarily in war industries were well handled. It was indeed fortunate that the fluorescent lamp, with its efficiency of light emission approximately double that of the incandescent filament lamp (or on the order of 35 to 40 lumens per watt in the U.S. and England), was well standardized, and in volume production when the European war began since night-time operations demanded prolongued usage of artificial lighting; since extra demands upon human vision spurred the installations of lighting wherein the footcandle values were more than twice the pre-war averages; where large savings in electric power for lighting systems were made available to electrical machinery and where far better illumination could quickly be had in factories and offices without re-wiring these structures with larger conductors.

Among the numerous engineering achievements in fluorescent illuminants that have occurred since the Munich pact of 1938, could be listed the following :—

1. The development of some six new shapes and sizes of fluorescent lamps to supplement the initial 15, 20 and 30 watt lamps, and comprising tubular units from 4 watt up to 100 watt inclusive. The standard line available in the United States, and in the main soon to be produced in England, comprises the following :

Watts.	*Bulb.*	*Base.*	*Hours Life.*	*Lumens.*
6	T–5 × 9″	Min. Bipin	1500	192 (white)
8	T–5 ×12″	,, ,,	1500	320 ,,
13	T–5 ×21″	,, ,,	1500	580 ,,
14	T–12×15″	Med. Bipin	2000	485 ,,
15	T–8 ×18″	,, ,,	Note	585 ,,
15	T–12×18″	,, ,,	,,	555 ,,
20	T–12×24″	,, ,,	,,	860 ,,
30	T–8 ×36″	,, ,,	,,	1440 ,,
40	T–12×48″	,, ,,	,,	2100 ,,
85	T–10, R. F.	Prong	3000	4000 ,,
100	T–17×60″	Mog. Bipin		4200 ,,

NOTE.—At six burning hours per start, average life is rated at 4000 hours. At three hours per start, life is 2500 hours, etc.

2. Improved phosphor coatings for the inside of the glass tubes which along with perfections in controlled quantities of mercury vapour and other gases, improved uniformity and efficiency. Supplementing this, better methods of applying the coating were developed.

3. Perfections in electrodes that involved better conditions of starting, a wider choice of currents (amperes), considerable betterment of average life and considerable reduction of the normal end blackening.

4. Development of the moulded plastic end cap or base, instead of one partially of metal.

5. The addition of four new sizes of so-called *Slimline* fluorescent lamps together with a new line of safety sockets and ballasting transformers to start these lamps at voltages in the neighbourhood of 600. This line introduces a lamp starting as a cold cathode device, i.e., without any pre-heating auxiliary starter but operating as a hot cathode lamp, the chief virtue of which is a high amperage and excellent efficiency. The standard tubular lamps to date are :

Watts.	*Bulb.*	*Base.*	*Hours Life.*	*Lumens.**
15 to 25	T–6×42″	Single Pin	2500	1400
23 to 38	T–6×64″	,, ,,	2500	2150
22 to 38	T–8×72″	,, ,,	2500	2350
30 to 52	T–8×96″	,, ,,	2500	3300

* Lumens at 200 ma. operation. The watt and lumen output depends on the chosen current which is usually 100 or 200 milliamperes (0·1 to 0·2 amps.).

6. The development of three circular or ring shapes of fluorescent lamps in diameters of 8¼ in., 12 in. and 16½ in., and primarily for use in the decorative field including auxiliary lighting in floor and tables portables.

7. Although shortage of cadmium and similar phosphor ingredients temporarily prohibited fluorescent lamp colours of pink or soft white (known in England as warm white) the lifting of these restrictions has recently started the replacement of the pre-war colours, plus the limited manufacture in the United States of a new white midway between the regular white and the daylight tints, namely, the 4500 deg. white. In conjunction with the elimination of the preheat starter and through the use of a high voltage ballast, there was added to the original hot cathode type of lamp a so-called instant start, 40 watt fluorescent lamp, using identical sockets and end caps but with the two contact pins joined together electrically.

From the start of the war, in order to simplify production and conserve materials, the fluorescent lamp manufacture in England was by agreement limited to a single design, namely, the 5 ft. by 1½ in. diameter, 80 watt, fluorescent lamp, producing 2800 lumens initial light output and having a normal rated life of 2000 hours. Both the thermal type and the glow type of starter were made available for operation on 200-250 volts. This one size was manufactured with the same bayonet two-pin double contact end cap that for some time had been standard for medium base filament lamps. With the end of the war, however, the British production of fluorescent types is planned to parallel the American sizes and wattages, and through the use of the bipin cap there will be interchangeability of all brands of standard fluorescent lamps in sockets of the new installations.

A limited production of a white fluorescent lamp closely duplicating the 80 watt English type was carried on in Germany but employing a push-in side contact and a special plastic end cap and socket. It is not known whether this design will be continued, but it is reported that both larger and smaller wattages of fluorescent lamps are planned for manufacture in Western Europe.

American research on high intensity mercury lamps continued with some temporary curtailments, chiefly those involving glass or quartz. Industrial demand led to wartime development of a 3000 watt, 120,000 lumen, medium pressure tubular lamp with a 48 in. arc and special end contacts burning through a transformer having an open circuit potential of about 800 volts. There was also continued development of the 1000 watt capillary high intensity mercury lamp, supplementing the previous water-cooled type but with an air-cooled design, while for limited lighting service the introduction was begun of a universal burning 400 watt, medium high pressure quartz mercury lamp designated type D-H1, especially intended for controlled high bay industrial lighting and for flood or street lighting.

In the line of improved street lighting, quite a large number of high intensity mercury lamps were installed in Great Britain just before war curtailments postponed the installation of new devices. With prismatic control glassware, these mercury units seemed to be successful. In the United States the standard 400 watt high intensity mercury lamp was giving a good performance in trial installations of street lighting after having had an excellent war-time record of performance in large area illumination of aircraft factories.

A new sunlamp was introduced in the United States, in the neck-aluminized 5 in. diameter reflector bulb, rated at about 275 watts and burnable in any standard lighting socket on 120 volt range alternating current. By virtue of having its ballasting done by an internal resistance filament, and a thermal relay, no separate current limiting transformer is required. Healthful ultraviolet was developed also by a small quartz bulb containing mercury vapour.

Emitters of short wave ultraviolet radiation, particularly usable for air sterilization, were developed from the standard hot cathode type of fluorescent lamp, minus the phosphor coating and using special high transmission glass tubing. The cold cathode tubular types of ultraviolet lamps expanded in application and were supplemented by a 2½ watt S-11 bulb lamp intended for reducing food spoilage and eliminating odours in refrigerator cabinets and similar closed spaces. Bent U-tube shapes of Sterilamps were developed for usage inside of milk cans and similar containers, while experiments continued toward developing special U-tube shapes for reducing athlete's foot spore in shoes or for usage in purifying gloves, hats, and other articles of clothing.

Coincidental with an expanded volume of filament lamp production was the constantly urgent engineering work of substituting available materials for those that became scarce or were needed for munitions, etc. Of chief importance were the applications of iron in place of tungsten or molybdenum lead wires within lamp bulbs, the use of iron instead of brass shell bases ; the developments of solder without tin, and the substitution of lime for lead glass. Many other substitutes were made and commendable engineering was exercised on both sides of the Atlantic, in keeping up the quality of the product in spite of a constant series of substitute materials, and of untrained workmen. Many unusual demands were made on manufacturers such as a sudden expansion of rough service or shock resistant lamps for fighting craft ; of special projection types of lamps as for gunsights and optical devices, and of special miniature types for signal purposes. An extension of roughened threads and similar methods to prevent lamp bases jarring out of sockets under conditions of ground shock or vibration, was a wartime need.

The requirements of protective or black-out lighting led to a sudden demand for blue bulb filament lamps in Western Europe and England—tapering off in later war years to more standard types plus, of course, numerous special shields and black-out accessories. Western Europe saw considerable usage of miniature sized gas mantles consuming about one-third of the normal volume of gas, but no research on gas lighting was apparent in America.

When on VE-Day there was a considerable renewal of flood-lighting, or when on July 15 Great Britain's street lights were generally turned on, conditions reverted to a close duplication of normalcy with surprisingly little delay or difficulty. Tribute of high order was earned by electric and gas undertakings which in England accomplished this in addition to the war-time maintenance of vital supplies, just as in the United States the co-operative engineering of utility companies avoided any shortage of electric power, and the " know-how " of electrical manufacturers met all reasonable wartime demands.

THE CAMBER BORING PROCESS.

By Dr. Gosta R. Truedsson, Consulting Engineer and Physicist.

Viewed from the standpoint of quality, there are few items of war production that rely upon high standards of precision more than do the aircraft engine crankshaft bearings. These silver-lined bearings operate under enormous unit loads, and under adverse conditions not normally found elsewhere in practice. At the outset of mass production for this item, not heretofore machined in large quantities, it became painfully apparent that our machine tool equipment, although quite adequate for the requirements of peace-time output previously existent, was not designed to meet the demands of the war. A method had to be found to eliminate the extensive hand labour involved in the conventional method of fitting every bearing into the engine and to reduce the element of human error, with the resultant high percentage of scrap because of the exacting accuracy required. Although the silver used for the bearing surface did not readily lend itself to the production of a smooth surface, the finish quality was an essential factor in attaining a high efficiency of lubrication in the engine. Furthermore, such results had to be obtained in volume production, despite infinitesimal tolerances and required surface finish to a profilometer roughness in the range of 4 to 6 micro-inches (r. m. s.).

It was also recognised that the ideal shape of the

Fig. 1. **Aircraft engine bearing with contour designed to relieve edge pressure from shaft deflection.**

bore should be approximately hyperbolic, or a combination of geometrical curves, in order to prevent edge pressure in the bearing from the elastic deflection of the crankshaft. However, to conform with previous practice a compromise taper-straight-taper contour was adopted for the bearings as indicated in Fig. 1.

It became obvious that the silver would not permit a grinding operation to be performed and retain a clean surface, with characteristics demanded for optimum conditions according to Reynold's hydrodynamic theory of lubrication, so the precision boring method, using a diamond cutting tool, was decided upon.

A special boring head, with an internal mechanism designed to produce the required taper-straight-taper contour bore in the work, was constructed as indicated in Fig. 2.

Here, the main tubular spindle (5) carries the cam sleeve (10) and is supported in three sets of oil bath lubricated bearings. The bearings (11) are of the sectional rocker-shoe type, commonly known as the Kingsbury or Michell bearing, and are backed by pivot type adjusting studs (12) in such a manner that the shoes automatically assume the most efficient running position for the production of the oil film.

The cam sleeve is free to move axially in the main spindle, but is restricted from relative angular movement by means of two keys (17) which are fitted into the keyways (18). It carries the contour cams (6) which are designed to produce the exact contour required in the workpiece (1).

The boring bar (3) is suspended on the fulcrum pin (4) which is preloaded in torsion to exert a stabilizing force against the loading pin (9), thus making for better conditions of boring. The boring bar is equipped with a follower and retraction trigger (7) to translate the cam contour to the workpiece when traversing the cam surface. The relative motion of the follower over the cam surface is produced by the machine table through two push rods (20) connecting the cam sleeve at the rear thrust unit.

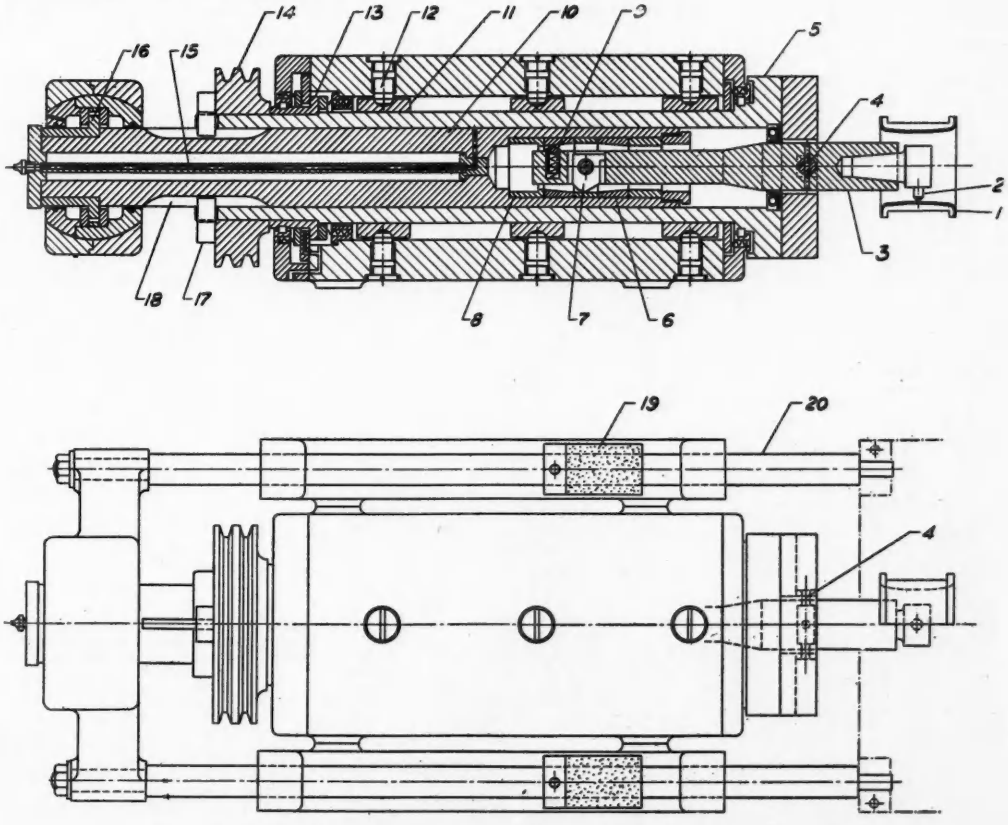


Fig. 2. **Boring head for camber boring of aircraft engine bearing.**

(1) Workpiece.
(2) Diamond cutting tool.
(3) Boring bar.
(4) Fulcrum pin.
(5) Main spindle.
(6) Contour cam.
(7) Follower and retraction trigger.
(8) Erection cam.
(9) Loading pin.
(10) Cam sleeve.
(11) Rocker-shoe.
(12) Shoe adjusting stud.
(13) Thrust bearing.
(14) V-Belt sheave.
(15) Lubricating tube.
(16) Thrust bearing.
(17) Key.
(18) Keyway.
(19) Rubber bumper.
(20) Push rod.

Retraction of the cutting tool from the bored surface is obtained during the return-stroke by a slight angular motion of the follower and retraction trigger, caused by friction against the cam surface, allowing the boring bar to deflect sufficiently to eliminate a drag line in the finished workpiece. The trigger is again erected at the start of the boring stroke, returning the tool to its original cutting position.

Due to the close fits required between the moving parts of the boring head, to meet the exacting tolerances of the work, forced lubrication and automatic temperature control was required. It was found that a relative temperature variation of 4 degs. Fahr. between the boring head and the work holding fixture displaced the bored hole sufficiently to cause rejection of the work due to eccentricity. For similar reason it was required to bore the work holding fixture in each machine, after the boring head and machine had reached their normal stable running conditions, while noting the relative temperature, which subsequently became the index for that particular machine. During normal production, the operator was thus required to set the thermostat, controlling the lubrication and cooling system, to the correct temperature and be on the alert for any abnormal changes in the machine temperature caused by draughts or other uncontrolled conditions.

The unsymmetrical design of some of the components of the boring head necessitated careful dynamic balancing of the entire assembly of rotating parts. A dynamic unbalance of a fraction of an ounce-inch, at 1500 r.p.m., was sufficient to show a detrimental surface condition in the highly sensitive silver lining in the workpiece.

Thus, the difficulties of dimensional control being alleviated, attention was centred on the metal cutting process. Extensive research and studies were required before all factors entering into the process could be fully evaluated and controlled so as to obtain optimum results.

The precision boring method, with its light cut at high surface speed and a fine feed per revolution, was particularly suited for the problem at hand. A machine of standard commercial design was used after minor changes had been effected. All vibration producing units, such as boring head drive, hydraulic feed system pump and lubrication and coolant systems, were detached from the machine proper and designed into a special outboard unit.

The diamond cutting tool was found to exhibit the properties required for the working of silver, but the formation of a hot continuous chip, due to the high ductility of the silver, presented a problem, as it immediately welded to the finished surface upon contact. Cutting lubricants or coolants had little effect upon the welding condition, probably due to the fact that the liquid could never reach the point on the tool where the heat was generated.

The best solution of the chip problem seemed to be the use of suction for removal of the chips as they were being formed, and this was combined with a chip separator for the convenient collection of the precious metal.

A clear conception of the problem may be gained by a study of photomicrograph, Fig. 3, which shows how

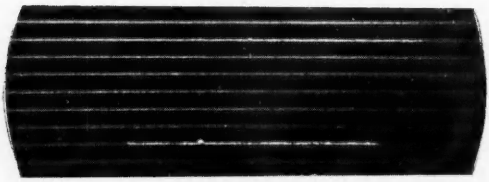


Fig. 3. **Photomicrograph (× 60) of bored surface, showing fragmentation and welding caused by the cutting tool.**

at some points the heat generated by the turning operation was sufficient to melt the metal at the ridges of the finished surface.

In order to duplicate, as far as possible, actual operating conditions in the aircraft engine, the workpiece was held in a hydraulic fixture with pressure applied as shown in Fig. 4. A similar fixture was also used at the inspection and checking stage, with pressures applied as specified by the user for the various bearings.

As we are living in a world of constant progress, where every advantage will be taken of our war-time experience to increase the productivity of our plants, it can be easily visualized how the camber boring process will find application in many allied fields, where bearings or other parts requiring some similar contour are employed.

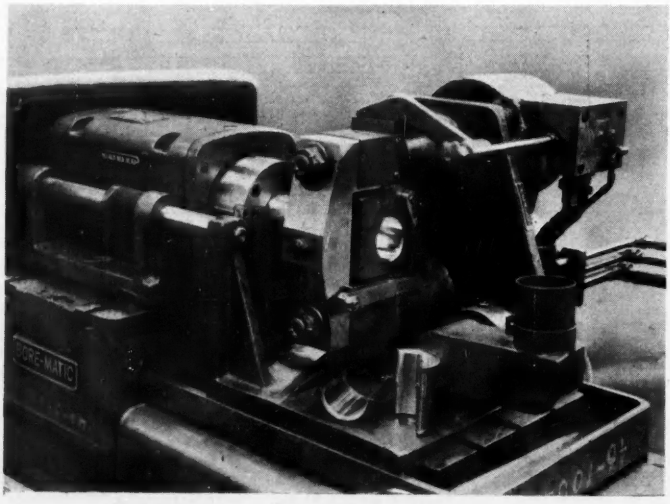


Fig. 4. **Precision boring machine with camber boring head and hydraulic clamping fixture for aircraft engine bearing.**

TECHNICAL ADVANCES IN SELECTED RAILWAY ENGINEERING FIELDS DURING WORLD WAR II.

By L. K. SILLCOX, First Vice-President, The New York Air Brake Company, Watertown, N.Y.

MOTIVE POWER.

IT is difficult, while standing close to any five-year period, to pick out a definite characteristic which will set it apart in the long and continuous sequence of locomotive development. The five years just past form no exception. The best that can be done is to make a few general statements and then see how they fit together in the broad scheme of things.

Five years ago the Diesel-electric locomotive had established a definite claim to superiority in switching fields where more than one shift a day can be operated. No change in this situation has taken place.

In road service the Diesel-electric has continued to attract a considerable amount of attention, and in new locomotives built the percentage of increase has been high. This is a matter of arithmetic, the total inventory of Diesel-electrics on which the increase is to be figured being much smaller than that of the steam locomotives. Growth in Diesel use is to be noted. Diesels have been introduced as freight locomotives and have given a good account of themselves, while the purchase of passenger Diesels has continued. A final balance cannot yet be struck to determine whether actual operating costs are sufficiently lower to offset the materially higher first cost. Operating conditions at present are, of course, abnormal, with every kind of locomotive being recalled from white-lead and reprieved from the scrap heap to be pressed into service.

Competition from the Diesel is helping users of steam locomotives to realize that efficient utilization of a locomotive is of first importance, and that this can be greatly improved and costs of operation reduced by providing proper service and maintenance facilities.

In the steam locomotive field we note the large amount of attention given to the 4-8-4 type, and at the same time the appearance of a number of novel types. Developments in transportation, such as increases in freight train speeds and increases in weights of passenger trains, have given great importance to the 4-8-4 type of locomotive. This type with from 65,000 to 70,000 lbs. on an axle, and from 260,000 to 280,000 lbs. on all driving wheels, serves well as an efficient all-round locomotive, able to work both passenger and freight service on roads with low to medium grades, and on roads with heavier grades to perform efficient passenger service. An excellent example of a modern 4-8-4 locomotive designed for all-round performance is provided by the New York Central Class S-1 locomotive. Built with driving wheels 75 or 79 ins. in diameter, an adhesive weight of 275,000, and over 4600 sq. ft. of evaporative heating surface, this locomotive has good, slow-speed hauling capacity and ample steaming capacity for high-speed work.

No special development is to be noted in design for freight locomotives of maximum hauling capacity. These are represented as in the past by articulated frame, four-cylinder, single-expansion locomotives of the 2-8-8-4 type.

Accompanying the tendency towards uniform acceptance of the 4-8-4 design, a number of designs are to be noted which represent definitely original thought. Of these the gas turbine engine of Bituminous Coal Research, Inc., is in the laboratory stage only. Two triplex locomotives, a steam-turbine electric-drive machine for the Chesapeake and Ohio and a steam-driven two-turbine direct-geared locomotive for the Pennsylvania Railroad, have appeared as artists' drawings, while a single-turbine, direct-geared 6-8-6 type locomotive is in service on the Pennsylvania and reportedly giving a good account of itself. Novelties which have very definitely arrived are the 4-4-4-4 type passenger and the 4-4-6-4 type freight locomotive, both developed for and by the Pennsylvania.

The 4-4-4-4 provides the same desirable characteristics as the 4-8-4 for heavy high-speed work, but has the added advantage of dividing the work between four instead of two cylinders. This makes for lighter stresses acting on the locomotive and the track. Steam distribution is also facilitated. The Pennsylvania 4-4-4-4 type locomotive, Class T-1, is equipped with the Franklin Railway Supply Company's system of steam distribution and poppet valves. Results with the first two locomotives of this class have been so satisfactory that fifty more are in hand. On the locomotive test plant at Altoona one of these engines developed 6500 h.p. indicated, with about 98,000 lbs. of steam per hour delivered to the engines. This represents 15 lbs. of steam per indicated horsepower-hour. At power below the maximum steam rates, as low as 13·8 lbs. per indicated horsepower-hour were obtained.

The other Pennsylvania Railroad engine of novel type now in service which appears destined to have successors is their Q-2 Class 4-4-6-4 type freight engine. This, like the T-1, is a rigid frame four-cylinder engine with four drivers in the front and six in the rear group. This provides 10 driving wheels for effective adhesion in freight service, and splits the power between two engines. The cylinders are equipped with piston valves.

The over-all situation seems to offer a satisfactory combination of maximum utilization of well-proved design and a forward outlook for further improvements.

WHEELS.

During the war period, the steel wheel industry of the United States has been called on to produce more wheels, both for domestic use and foreign shipment, than ever before. All of the six wheel mills have been worked to maximum capacity. Their production was greatly helped by standardization of designs and specifications which was put in force by an order of the War Production Board.

The research work of the industry has been carried on very actively throughout the entire period, both by individual companies and by the Technical Board of the industry which made use of the laboratories of the University of Illinois. While the quality of the product has been such that very few accidents have occurred due to defective wheels during this period, it was recognized that the post-war railway operation would involve even more severe service conditions, particularly as regards heat effects from breaking involved in higher speed operation. The research was particularly directed towards the study of stress build-up produced in the plates of wheels by brake shoe heating. Two other features were investigated, namely, the chemistry of the steel and the details of the design of plate, fillets, etc., of the wheels. These studies produced valuable information, and many of the results were immediately put into practice in the mills. Some of the design detail studies have not been completed, but should be available in time for application in this post-war period. It is believed that with the knowledge now available, it is possible to manufacture steel wheels which will fully meet the exacting requirements of the post-war operation of locomotives and cars.

The requirements for suitable wheels for Diesel locomotives, steam locomotives, passenger cars, and freight cars are all different · it has been found necessary to use different types of wheels for these various services

whereas in the pre-war period, the same general type of wheels was used for all services.

In connection with the other research work, a large amount of study has been given to the methods of heat treating wheels, and ways have been found to improve this procedure, particularly the effect on residual stresses in the wheels. The old theory was that the wheel should be as near stress free as possible, but it has been found that stresses in the proper direction, particularly those in the wheel rim, are helpful in offsetting stresses produced by brake shoe heating of the rim. The railways have gradually come to use more and more heat treated wheels. Now in the post-war period, it appears that practically all wheels will be heat treated with the possible exception of freight-car wheels.

Another development of interest is that it has been found possible, through the study of stresses in wheels, to reduce wheel weight by eliminating metal in certain parts where it has been found unnecessary. This applies particularly to the hub and plate sections.

In general, the technical work done during the war has resulted in the production of better wheels, and an increase in the output capacity of the plants. It appears that the industry is in an excellent position to meet all of the difficult service requirements which can be foreseen for the post-war period of railway operation.

STEELS.

One of the most important advances in steel for railway use has been the application of high-strength steels for structural parts of freight and passenger car bodies. These atmospheric corrosion-resistant, high-strength steels have relatively low contents of alloys, with but moderate advance in unit price over carbon steel.

Beginning in 1934 principal steel producers in the United States introduced several compositions of this steel, which as furnished, without special treatment subsequent to rolling, provide a high yield point and endurance limit, on which design stresses are generally based. While possessing superior ductility, impact strength, and weldability than can be obtained in carbon steel of equivalent strength, these steels have adequate workability so that conventional methods of fabrication can be utilized, and their application is possible in constructions similar to those employing plain structural steel of relatively low carbon content.

The trend to substitute high-strength, low-alloy steel for the conventional equipment of plain carbon or copper steel in freight and passenger cars was interrupted by the war. However, 10 years of testing and service experience have demonstrated the prime benefit of the high-strength steels—that of weight saving without loss of service life. Reduction in weight of freight cars decreased the ratio of tare ton-mileage of vehicles to net ton-mileage of paying load; and in the lighter passenger cars, higher speeds or longer trains were made possible without increased motive power. This saving of weight in structural members has largely offset the increased unit costs of the steel employed. Obviously, high-strength steels for light-weight structures would not be possible if alloying elements could not be employed to insure against corrosion; and striking cases are on record illustrating the part which resistance to corrosion plays in assuring a long service life.

Diversified application of war equipment afforded confirmation of the versatility of low-alloy, high-strength steels for structural uses under most widely varying conditions of service. Now that supplies of alloying elements have become adequate, railways are resuming the use of these steels for freight and passenger cars, and designs are now in process to establish light-weight standards for various common types and sizes of freight equipment built of these strong and corrosion-resistant materials.

Details of the compositions and properties of the major American high-strength low-alloy steels are shown in Table I. An evident characteristic of all steels in this class is the use of copper in percentages exceeding that present in widely used carbon-copper steel. A notable innovation in some of the compositions is the deliberate addition of phosphor and silicon to serve as strengthening elements. Other common alloying elements—chromium, nickel, and molybdenum—are utilized in small percentages and usually in combination.

TABLE I. COMPOSITION AND PROPERTIES OF LOW-ALLOY HIGH STRENGTH STEELS.

		Chemical Composition. Per Cent of Elements.									Physical Properties.		
Producing Company.	Designation.	C	Mn	P	S	Si	Cu	Cr	Ni	Other Elements	Yield Point lb./sq. in. min.	Tensile Strength lb./sq. in. min.	Elongation in 2", %
United States Steel	Cor-Ten	0·12 to max.	0·20–0·50	0·07–0·15	0·05 max.	0·25–0·75	0·30–0·70	0·50–1·25	0·55 max.		50,000	70,000	22 min.
Bethlehem Steel Co.	Mayari R	0·12 max.	0·50–1·00	0·08–0·12	0·05 max.	0·05–0·50	0·50–0·70	0·20–1·00	0·25–0·75				
Republic Steel Corp.	RDS No. 1	0·12 max.	0·50–1·00	—	—	—	0·50–1·50		0·50–1·25	Mo 0·10 min.	55,000	70,000	25 min.
" "	RDS No. 1A	0·30 max.	0·50–1·00	—	—	—	0·50–1·50		0·50–1·25	0·10 min.	70,000	90,000	15 min.
Ygnstn. Sheet & Tube Co.	Yoloy	0·05–0·35	0·30–1·00	0·04 max.	0·05 max.		0·90–1·25		1·50–2·00		53, – 85,000	68, – 105,000	27–17
Amer. Rolling Mill Co.	Armco 50 Y	0·12 max.	0·50–0·75	0·04–0·07	0·04 max.	0·10 max.	0·50–0·70		0·60–0·90		50, – 60,000	65, – 80,000	32–20
" "	Armco 55 Y	0·12 max.	0·65–0·95	0·07–0·12	0·04 max.	0·10 max.	0·50–0·70		0·60–0·90		55, – 70,000	75, – 90,000	27–15
Inland Steel Co.	Hi-Steel	0·12 max.	0·50–0·70	0·10–0·15	0·05 max.		0·90–1·25		0·45–0·65		55,000	70,000	20 min.
Great Lakes Steel Corp.	N-A-X	0·10–0·18	0·60–0·75	0·04 max.	0·05 max.	0·60–0·90	0·25 max.	0·50–0·65		Zr. 0·05–0·15	50,000	70,000	32 min.

AMERICAN SHIP DESIGN AS INFLUENCED BY THE WAR.

By Vice-Admiral EMORY S. LAND, U.S.N. (Retired), Chairman, United States Maritime Commission and Administrator, War Shipping Administration.

SHIP designs created under direction of the United States Maritime Commission in almost every case were the result of a condition of the times. In almost ten years—the Maritime Commission was created by the Merchant Marine Act of 1936—shipbuilding in the United States made a complete cycle through a programme designed primarily for the purposes of peace to one geared to the excessive demands of war and back again to peace.

American ship design followed these conditions. The vessels the Commission began to build in 1938, its famed C-types, were designed to raise the United States Merchant Marine from one of its lowest points to a competitive position among the world's merchant fleets. The threat of war and final embroilment of the United States in the conflict brought new designs, new methods and techniques of shipbuilding, and a resultant volume of tonnage that places the United States in possession of about two-thirds of all the shipping afloat.

A great number of modern and fast vessels are in this fleet, in addition to the 2600 or more emergency Liberty ships that were built. Yet the fleet is not completely balanced for want of passenger vessels, combination cargo-passenger types and special vessels for certain cargoes and trades. The vessels that now are under construction or are contemplated are principally in these categories, with considerable reconversion of existing vessels to those purposes under way or in the offing. The ship design of the future will incorporate all the lessons learned from wartime construction and operation. So, to understand the influence the war wielded over ship design it may be well to incorporate some recent shipping history as we go along.

American shipbuilding, in the period between the two wars, was uneven in tenor. Principally, it was because of lack of a definite, far-seeing policy. When shipbuilding for the previous war ended in 1922, the United States possessed a merchant fleet deemed adequate for the times. In the years following a maritime error of the first magnitude was committed. There was no provision made to sustain shipbuilding sufficiently to keep the industry mobilized or the fleet modern. Though a few passenger-cargo vessels were built for specialized trades, and considerable maritime legislation was enacted in an attempt to correct the more obvious evils that crept into the shipping industry, only two general dry cargo vessels were built between 1922 and 1936, when the Commission was established.

Consequently, when the Commission found by a survey of the Merchant Marine in 1937 that more than 90 per cent of the existing fleet would be obsolete in 1942, the obvious need was for a sustained building programme. It was a demand of the times, and called for strong and vigorous action. The Commission instituted its long-range programme, out of which came the C-types, consistently recognized as one of the substantial American contributions to ship design.

These were, and continue to be, the standard product of the Commission. Though events compelled the United States to build several other types in order to meet special conditions, the building of C-vessels was continued throughout the war period, and, with Victory ships, constitute the nucleus of the American post-war merchant fleet.

In considering the war-inspired changes in ship design, it may be proper to view the entire building programme of the Commission as a war project. For no sooner were the first ships of the long-range programme delivered in the summer of 1939, than events in Europe led the Commission to double and then redouble its building schedules. The original programme called for 500 ships to be built at the rate of 50 per year. By the time the United States was attacked, the schedules called for 400 per year.

Also, by this time the pinch of insufficient shipping was becoming much tighter. The United States had committed itself to the lend-lease principle in the Spring of 1941. The entire anti-Axis world was increasingly dependent upon the American Merchant Marine. The C-types were not the answer to an overwhelming demand for tonnage. Too much time was required for their construction.

The answer was found in the Liberty ship. Methods and technique discovered by which these vessels could be assembled in days rather than months raised the two-year total of ship production in American yards in 1942 and 1943 to more than 27 million deadweight tons. Liberty ships are admittedly slow and economically inefficient. Yet they bore the brunt of the war's shipping load. They were the product of dire need, and they led the shipbuilding industry into the Victory ship, one of the significant advances in ship construction to come out of the war. For the Victory is a fast, modern ship, with fine lines, modern propulsion and speeds, according to power, up to 17½ knots, yet adaptable to mass assembly methods of construction.

Thus another special situation created by abnormal conditions was met and solved. Liberty ship production rose to its peak at the end of 1943. By this time all the ship losses of the United Nations had been replaced. Thereafter, the Commission gave marked attention to the building of faster ships, many of which were constructed as, or converted to, military vessels, to enable rapid and effective deployment of troops; and in some cases merchant hulls emerged as special fighting vessels.

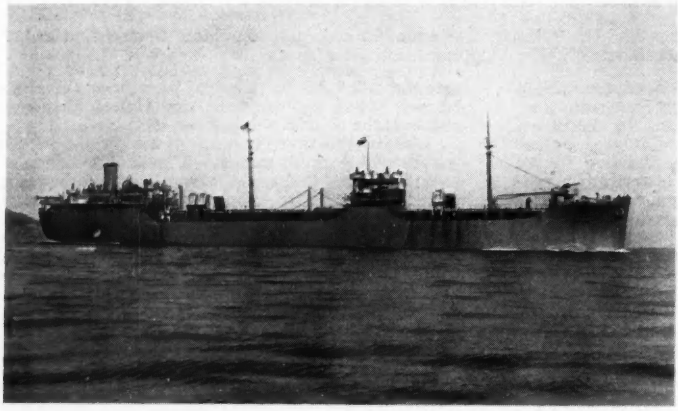
A considerable number of merchant ships became transports. Others became small aircraft carriers, the "baby flat-tops." Victory ships and C-types were completed by the Navy as combat cargo and combat transport ships. Small vessels were developed for inter-island transport in the Pacific. Frigates, tenders and oilers were delivered in considerable numbers in 1943 and thereafter. Merchant shipyards were able to turn to this construction with comparative ease, because of the "know how" acquired in the few years of shipbuilding revival, and these military types contributed substantially to the outcome of the war.

With this brief summary of shipbuilding as it was affected by world events, we reach discussion of ship design and the improvements that evolved to meet changing situations. The peacetime needs of the merchant fleet have not been entirely fulfilled by the wartime building programme, for, by necessity, construction of passenger vessels was precluded by the war, and certain other types, such as refrigerator ships and specialized vessels continue in need.

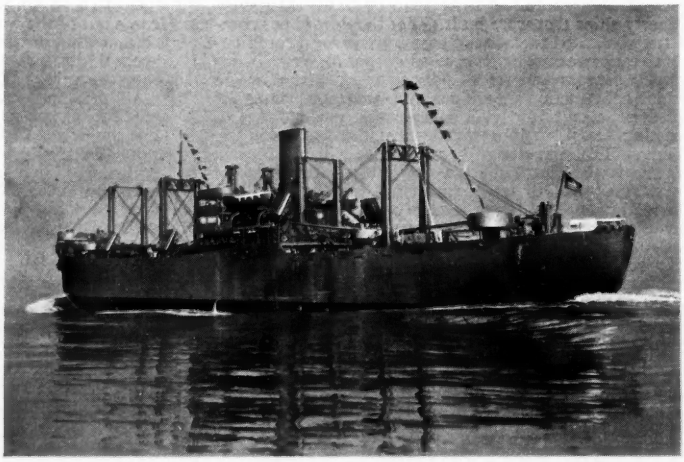
When the Commission was originally organized there was considerable discussion as to the wisdom of designing standard types, it being held by many that in order to secure effective service a ship should be designed around the immediate requirements of the trade route in view, together with the policies of competing lines and the characteristics of vessels which the competitors had already placed or contemplated placing on the trade routes.

However, after building the "America," a large liner, the Commission came to the conclusion that the best interests of the nation demanded new cargo vessels of a general type, rather than specialized vessels for certain cargoes or trades.

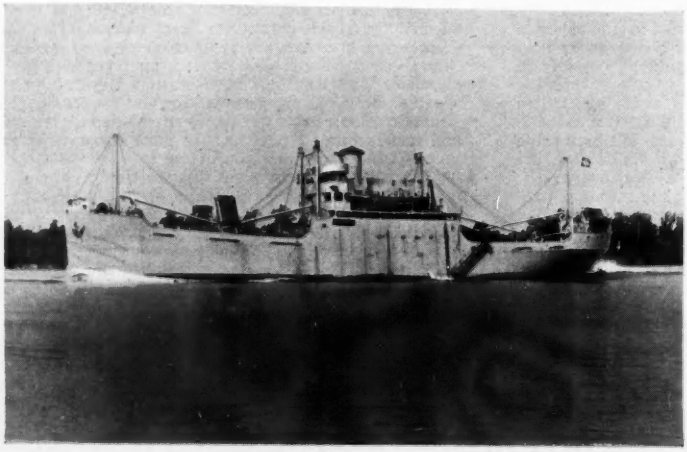
It is provided in the legislation responsible for



First Marinship tanker to be delivered fully equipped to the Maritime Commission, the SS Mission Purisima a T2-SE-A2 tanker cuts through the waters of San Francisco Bay.



C2-S-B1 type freighter SS Hotspur.



Trial run of the N3-S-A2 SS. Edward Nickels.

creating the Maritime Commission that the Commission shall design efficient vessels capable of rendering satisfactory service as auxiliaries in time of national emergency. When the designs were submitted to the Navy Department for consideration prior to the placing of contracts, the contemplated speed received particular attention. By mutual agreement 15 knots was accepted as meeting the minimum needs of the Nation. In only one class of vessel, the C-1, did the Commission propose a speed under 15 knots. Fourteen knots was accepted with reluctance because of economic justification.

In addition to the speed requirement, it was accepted as basic that Commission-designed vessels should provide adequately for the working and living conditions of sea-going personnel. As a result of a careful study of working and living conditions in American vessels already in operation, standards involving the area of floor space, and location in the ship, the type of berthing the food preparation and service, etc., were developed which, in recent years have combined to secure for the American seaman comforts at least equal to and in many respects superior to those enjoyed by the seagoing personnel of any other nation.

In all standard C-types crew accommodation are located in the midship structure and above the weather deck, doing away with the old focs'le and poop segregation. In general, no more than three persons are assigned to one stateroom and a separate stateroom is provided for each licensed officer. Separate messrooms are provided for crew, petty officers, and officers, each properly equipped with pantries, etc., and sufficient to seat the full complement at one time. Sanitary facilities in excess of usual standards ; proper lighting, heating, and ventilation ; ample provisions for hospital, ship's offices and store spaces make the available accommodations entirely adequate.

The most careful consideration was given to the problem of propulsion. The power range of the standard C-type ships lies between 4000 and 8500 h.p. Electric drive for these vessels was investigated ; however, the economics of the power ranges considered indicated that the loss in efficiency due to power transmission and the increase in weight of machinery did not justify adopting this type of propulsion.

Both Diesel and steam were given the most careful consideration. In the Diesel field contracts were placed for both direct drive machinery and for main units of higher revolutions operating through reduction gears with electric coupling. In general, it may be said that both types have rendered acceptable service.

For steam propulsion, in the power range considered, the Commission adopted a pressure of 450 lbs. with total temperatures of 750 deg. All of these installations have been turbines with mechanical reduction gearing so designed to give a range of propeller r.p.m.'s suited to high propeller efficiency. These installations are also characterized by their excellent results in service as to reliability and low fuel consumption.

The C-2 was the first of these types to be designed. It met with considerable favour, for it attained an excellent balance of speed, cargo capacity and operating economy. The improved living quarters met a major objection from seamen. Individual rooms and accommodations for the chief officers and commensurate facilities for others of the crew raised shipboard living standards to attractive levels.

The C-3 was the second design of this type prepared by the Commission. It satisfied the need for greater deadweight capacity and greater speed, and lent itself well to variations in design to meet special cargo and trade requirements. It is perhaps the best known ship of this type, and it probably has been adapted to more uses than any other vessel ever constructed. Outstanding in these conversions are the following types :— Escort aircraft carriers, destroyer tenders, seaplane tenders, passenger and cargo vessels of four types, attack transports for the Navy, troop transports for the Army, besides multitudinous minor modifications made pre-war to suit the requirements of various operators on standard trade routes. Although designed as 16½ knot vessels, these ships have been scheduled regularly at 17 or 17½ knots, and have proven capable of maintaining this speed, and there are records wherein there has been attained on certain routes an overall speed of 18 knots where such a voyage has been aided by favourable winds and currents.

There are two types of C-1, namely, the C1-A and C1-B. The C1-A was the earlier design, and like the C-2 vessels was designed as a shelter decker. Before placing contracts, however, the Commission received comments from many operators who felt it would be desirable to have a vessel of this size and speed for use in the deadweight trades. There was sufficient interest shown in a vessel of this type so that the C1-B was designed as a full scantling vessel. Both types have seen considerable service and proven satisfactory for the trades for which each was suitable. Fewer changes have been introduced in these than in other types primarily because of restrictions imposed on conversion due to their smaller size. Also there is a lack of flexibility in operation because of the slower speeds compared to the other standard types.

We may pass over the Liberty ship programme with but brief mention. Most of the shipbuilding industry is familiar with the fact that it is an adaptation of the British Sunderland design, and was inspired by the 60 vessels of that type that were built in the United States for British account in 1941-42-43. The Commission became convinced that with a minimum of changes this design could be adapted to a high degree of standardization and prefabrication. The first two of these vessels were delivered before the close of 1941, and such was the efficacy of the building methods developed for Liberty construction that the average all-yard building time for these vessels fell from 241 days in January, 1942, to 39·2 days for the month of December, 1943.

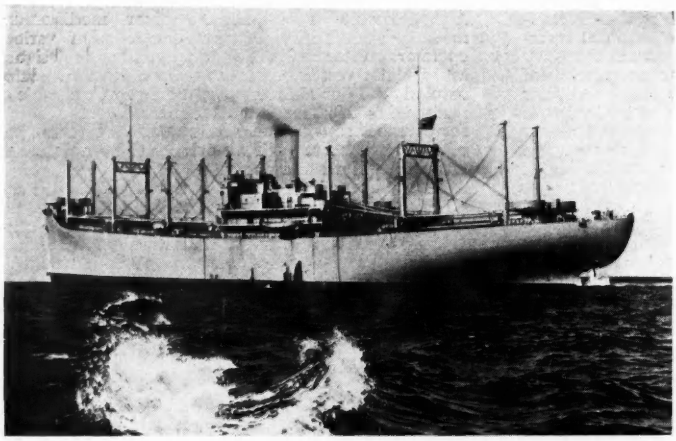
Out of the Liberty programme came the Victory design. The two are entwined in some respects, therefore the characteristics of both may be reviewed somewhat, so that the evolvement of the Victory may be a little clearer.

The Liberty design was accepted by the Maritime Commission because it was essentially sound, and the detail working drawings well advanced, the purchasing of materials in quantity well organized and underway at the time when the Commission was confronted with the necessity of turning out a large amount of cargo ship tonnage in record-breaking time. The Liberty was the obvious answer to the then immediate and very urgent problem of cargo ship tonnage in quantity. The Liberty ship is about 10,500 tons deadweight, on a draft of about 27 ft. 10 in. Its sea speed loaded is considered to be 11 to 11½ knots. This was recognized at the time of the design acceptance as undesirably low. However, the power plant, 2500 i.h.p. steam reciprocating machinery, could be turned out in quantity with a reasonable degree of promptness and without undue interference with other building programmes already operative.

There was then no alternative ; the Commission adopted the Liberty ship and proceeded to build. By the end of 1942, there were 544 Libertys at sea and many more under contract in the building yards of the country.

There were those who were not satisfied with the Liberty ship, principally because of its slow speed. As the submarine toll of Allied shipping increased, criticism also increased.

It was believed, partly as the result of actual experience, that a service speed of 15 knots might enable a vessel to navigate most routes without convoy, and yet enjoy comparative freedom from submarine attack.



Sea Porpoise, C3-S-A2, Ingalls.

It was felt further, that 15 knots would be sufficient to make a ship of value in commercial service after the war. The form of the Liberty ship was not suited to economic driving at speeds in excess of 13½ or 14 knots. Accordingly, it appeared necessary to develop a new hull.

Because of the urgent demand for tonnage and the experience with other vessels already in service, the Commission decided that the deadweight capacity of the new ship must at least equal that of the Liberty.

There were two requirements then : a service speed of 15 knots in fully loaded condition and a deadweight capacity of not less than 10,500 tons. This became the basis for the Victory ship design.

Investigation showed that the shaft horse-power necessary to meet these requirements would be at least 5600 and perhaps as much as 6000. This conclusion made it possible to examine the then existing possibilities of propulsion machinery production.

At this time—the fall of 1942—facilities for manufacture of propulsion machinery were much greater than at the inception of the Liberty ship programme. However, they were not equal to delivering C-2 type turbine mechanical reduction-geared installations in the quantity and time considered necessary, without interference with other building programmes. Therefore, the possibilities of the uniflow, the Lentz and the Diesel types were carefully weighed. The decision was to use a number of Diesel units and to develop plans and specifications for a large Lentz engine so that a trial unit could be built and carefully tested prior to turning it out in quantity. The Victory ships would then be driven by mechanical reduction-geared turbines, direct drive Diesels or by direct drive Lentz machinery installations.

At about this time a discussion of a possible new type of ship was held with a representative of the American Bureau of Shipping. There was furnished to the Commission the result of a study relative to certain important elements of design, all intended to simplify building. This discussion contemplated a vessel with uniflow engines and a hull of 12 ft. longer than the C1-B, and having a speed of about 13 knots. In addition, it proposed to improve the structural design of the Liberty type ship.

The C1-B type of ship was recognized as meeting the demands of certain owners very satisfactorily. Moreover, a modification of this class to utilize an inexpensive type of machinery would have led to a ship having a genuine appeal under peacetime conditions. However, the 13 knots proposed would not have permitted operation without convoy.

Further, throughout the year 1942, the demand for cargo carrying tonnage without limit was insistent. There could not be too much. Inasmuch as it is not materially more difficult to construct a 10,500-ton ship than one of 9,500 tons, it was obvious that the emergency could best be met by designing for the deadweight and speed previously decided on. The suggestions relative to structure were carefully studied and eventually adopted.

As it finally evolved, the Victory is of steel construction, arranged for the freighting of dry cargo in five main holds with deep tanks for fuel oil or ballast ; and with a full raised forecastle, midship house and superstructure, and poop house, two complete steel decks known as the main and second decks, with a platform deck forward of the machinery space and platform deck aft in No. 4 and 5 holds at the level of the top of the shaft tunnel. The stern is of cruiser type in conjunction with full contra-rudder, rudder post and stern post. The stem is raked and straight with paravane skeg fitted on the forefoot. Drive is through a single screw from propulsion machinery located amidships.

The hull is sub-divided by seven full main watertight bulkheads extending watertight to the main deck, except the forepeak bulkhead which extends watertight to the forecastle deck. Further sub-division provides deep tanks below the flat in No. 4 and 5 holds, each side of the shaft alley for fuel oil or ballast water.

Complete cargo handling gear for all hatches is provided on steel masts and kingposts with No. 3 and No. 4 hatches double ganged. Topmasts are fitted on masts. Heavy lift hoisting booms and rigging are provided on centreline deck pedestals aft of foremast and forward of main mast.

Dry and stewards' stores, soiled linen locker, laundry and CO_2 room are provided on the second deck abreast of machinery casing port and the ship's refrigerated spaces are on the starboard side. Accommodation and berthing spaces are steam-heated, and provided with adequate ventilation, toilets, showers and lavatories with hot and cold running water.

In its long range programme, as originally laid out, the Commission had endeavoured to provide as large cubic capacity as practicable, and therefore, had generally adopted the shelter deck. Later, however, with the undertaking of the C-1 type, there had developed on the part of ship operators a demand for deadweight. This resulted in the development of the type known as the C1-B, which has a full scantlinged hull and relatively deep draft. The Liberty type ship was also full scantlinged, and the cargo furnished in the earlier days of

the war was largely a deadweight rather than a cubic cargo. It is because of these considerations that the Victory type ship is developed as a full scantlinged vessel. Naturally, the figure for cubic feet per ton of cargo is not as large as for a shelter deck type.

Effort has been made to secure cubic capacity sufficient for the cargo deadweight involved. Further, good clear deck space outboard of the hatch line is provided so as to permit the carriage of a reasonable deck load so important in war time and essential in many peace-time trades.

At the time of the inception of the design work in connection with engineering features on the Victory ships, the problem of obtaining suitable propulsion machinery was paramount. Some machinery of the C-3 type was available, but not enough to satisfy a large building programme. After careful consideration and conferences with outside experts, it was agreed that if the Commission would be willing to sacrifice something in the line of economy and lower some design factors slightly, the manufacturers would then be able to make delivery of 6000 h.p. propulsion units with greater rapidity than heretofore possible. The Commission decided that this sacrifice of economy for added production would be advisable, and thus the Victory turbine unit was born.

The Victory ships in reality, consist of two entirely different main propulsion plants. The Commission had previously placed pool orders for main turbines and gears for the C-3 types. This power plant required turbines developing 8500 s.h.p. Due to improved production methods of the turbine and gear manufacturers, this type of propulsion had been manufactured faster than our C-3 type vessel could absorb it. Therefore, in laying out the Victory hull, a hull form was decided upon that would be able to accommodate the 8500 s.h.p. power plant as well as one of 6000 h.p. The design of the Victory ship incorporating the 8500 s.h.p. machinery is known as the AP-3 design and that incorporating the 6000 s.h.p. machinery is known as the AP-2 design.

The AP-3 design was considered basic, and the AP-2 design was developed from it. This pertains to the auxiliaries to a very large extent. The rule was followed of sizing the auxiliaries to take care of the larger h.p., and then pool orders were placed for duplicate auxiliaries in order to obtain the best production of such equipment. Furthermore, in connection with the 8500 s.h.p. turbines and gears, it was endeavoured to schedule the same designs of turbines and gears to a given yard as far as possible in order to lessen the installation difficulties.

The 6000 s.h.p. propulsion machinery was standardized to some extent so that interchangeability of units could be realized. The Victory turbine represents months of study and effort by the outstanding turbine and gear manufacturers of the country. Even after such an exhaustive study was carried through, it cannot be stated that a completely standardized set of turbines and gears was obtained. First of all, many compromises were of necessity made which prevented the complete standardization of these units. Different basic designs, differences in shop tooling and in manufacturing methods prevented the realization of complete standardization. Therefore, it was deemed advisable to accept units manufactured by the different turbine and gear manufacturers permitting them to design the internals in accordance with their previous practices and utilizing their different shop methods, and requiring each to meet certain over-all dimensions and also common foundations, as well as a given standard condenser.

A crane's eye view of Liberty ship being given final touches at the outfitting dock.

Below are given details showing the pounds of fuel consumed per s.h.p. for some of the Maritime Commission vessels :—

Liberty Ships	1·3 –1·4
C1-B	·60– ·63
C-2	·59– ·61
C-3	·57– ·59
AP-2	·66
AP-3	·59

From the above it can be seen that Commission technicians were not entirely happy with the economy on the AP-2 design, but it can also be seen that a big improvement in economy was made over the Liberty vessels.

The American tanker fleet also underwent a phenomenal growth during the war. Yearly tanker production soared from 11 built in 1939 to 219 in 1944. This, of course, was the result of the insatiable demand for oil products on all war fronts.

The Commission's tanker programme was essentially a continuation of the private building of tankers, so far as design is concerned. One of the Commission's first acts was to make provision for gun emplacements, oiling-at-sea-gear and for stepping up speed on the tankers building in the early days of the Commission's existence.

This last factor has been of immense importance, for the speed of tankers in those days generally was around 12 knots. In considering the defence angles, this speed was entirely too slow. Therefore, particularly at the insistence of the Navy, and also for general reasons, the Commission's designs came to call for speeds up to 18 knots.

A significant development of the tanker programme has been general acceptance of these speeds in operating practice by oil companies, for it was found that a fast ship was more economical in the long run than a slower vessel of lesser operating cost.

The Commission's T-3 tanker has essentially the same specifications as the so-called National Defence Tanker equipped by the Commission in 1936-37-38. It is a twin screw, geared turbine vessel of 6750 s.h.p. on each screw. In 1942 there was developed the T-2, a single screw, turbo-electric vessel, developing in one version 6000 to 7500 s.h.p. and in another version 10,000 s.h.p. This ship has a length of 523·5 ft., a 68-ft. beam and deadweight of more than 16,000 tons.

There was also developed a small coastal tanker, the T-1, a Diesel-driven light draft vessel for shallow waters.

In the field of smaller vessels, the war brought two developments that were of considerable consequence to the military, especially in the Pacific war, where shallow ports and island waters made light draft and small ships imperative.

The Commission's N-3, developed from a British design, was in its original form a coal burner type of the North and Baltic Seas. The American version became an oil burner, its reciprocating steam engine developing 1300 i.h.p., providing a speed of 10·5 knots. It is 259 ft. long, with a 42-ft. beam, draft of 17 ft. 11 ins and deadweight of 2738 tons. More than 80 were built.

In greater numbers were the CM-M-AV1, which the military found particularly essential in the later days of the war. It is a small vessel with a L.B.P. of 320 ft. and a 50-ft. beam. It draws 21 ft., and has a deadweight of 5020 tons. Propulsion is a direct Diesel drive, rated at 1700 s.h.p. at 180 r.p.m., providing a speed of 11 knots. More than 240 of these were built, most of them taken over by the Navy.

So that we may have a ready compilation of the characteristics of the principal types of vessels that will compose the American post-war merchant fleet, the following table is shown:—

	C1-A	C1-B	C-2	AP-2
L.B.P.—feet	390	395	435	436
Draft—feet	23·5	27·5	25·75	28·5
DWT.—tons	7,271	9,398	9,036	10,800
S.H.P.	4,000	4,000	6,000	6,000
Designed Speed—Knots	14	14	15½	15½
Bale Capacity ..	448,995	447,748	560,000	453,210

	AP-3	C-3	C-4	P2-R3
L.B.P.—feet	436	465	496	590
Draft—feet	28·5	28·5	30	30
DWT.—tons	10,700	12,120	15,300	12,350
S.H.P.	8,500	8,500	9,000	18,000
Designed Speed—Knots	17	16½	16½	19½
Bale Capacity ..	453,210	730,000	736,520	332,000

On October 1, 1945, the War Shipping Administration had under its control 4363 ocean-going vessels. With others to be returned from nations to which they had gone under wartime agreements, and from military service, there will be well over 5000 vessels in the American Merchant Marine. More than half of them will be Liberty ships, whose final disposition depends on factors that cannot be resolved at once. The Maritime Commission for some time has been studying the aspects of the international post-war shipping situation, and is taking what steps it can to help the industry convert itself to conditions as they develop.

Thus we come to the post-war aspects of the American Merchant Marine, and to discussion of how these designs can be adapted to our needs. We have reviewed the principal types of vessels that will be under the American flag in the post-war era. C-2 and C-3 vessels have been built all during the war period with few basic changes, so that they retain their adaptability to variation, and the Victory ship is also adaptable to variation to some degree.

The C-2 types and Victory ships of the AP-2 type may be considered as a family as they have many characteristics in common. The speeds are approximately the same. The C-2's possess a somewhat large bale capacity as may be noted in the tabulation. Thus the C-2 is adaptable to general cargo trades, particularly package freight, whereas the Victory ship could be considered better suited to routes where deadweight or bulk cargoes are to be found.

It was possible to make slight compromises and use the same hull for both the AP-2 and AP-3 types, with excellent performance for this range of powers despite the resultant variation in speed. This vessel can well be utilized in deadweight trades where speeds are important, especially those involving voyages of a considerable length. Although there are not as many AP-3 vessels available as the slower AP-2's, as a considerable number have been converted for the Navy's use as combat transports, it is possible that some of these may be returned to the Commission for reconversion for post-war use. It may be stated here that many of the standard types are in a similar category, i.e., after the need of the military has been accomplished, they may become available for re-conversion under somewhat favourable conditions from a standpoint of general financial outlay.

As illustration of what may be done in adapting C-types to the maritime needs of the United States, a summation of conversions which have been made, or are in the making, may serve to show the remarkable flexibility of the design.

For the Grace Lines two sets of C-2's have undergone changes, including additional cargo-handling gear providing double ganging of cargo hatches and a doubling of boom capacity for midship hatches. Also, about 100,000 cub. ft. of refrigeration especially adapted for carrying of bananas was added in No. 2 and No. 4 upper and lower 'tween decks. The second conversion proposes accommodations for some 52 passengers. By modifying superstructures above the main deck the necessary staterooms, a dining room, lounge, cocktail room and open-air swimming pool can be arranged. With addition of cargo carrying space and reduction for passenger accommodations, the deadweight capacity is approximately 10,000 tons.

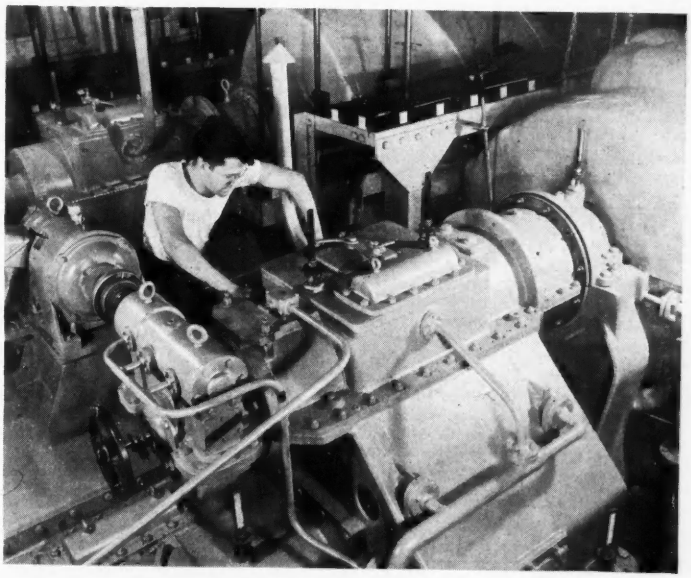
Changes of C-2's for the U.S. Lines have not been so extensive. Regrigeration is primarily for frozen produce and limited to No. 3 and 4 upper 'tween decks. Additional deck tanks have been added to insure cruising radius. The resulting bale cubic is approximately 426,000 for dry cargo, 37,000 for refrigerated, and deadweight 10,400 tons.

In addition to the above specific changes many C-2's were modified in cargo handling rig, and most of them assigned to regular trade routes had refrigeration added.

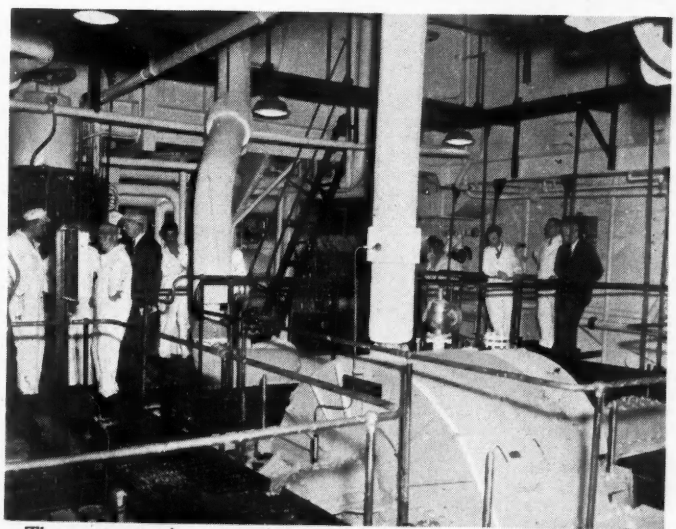
Many C-3's have gone to the Army and Navy. Before the war several of this type were modified for the American President Lines in the round-the-world trade to replace older vessels. Though the war intervened before they could be placed in service, the operating experience gained indicated they would have been successful. The passenger accommodations consisted of 38 staterooms, a lounge and spacious foyer, a swimming pool and large dining room, well ventilated or air conditioned.

The Commission was also arranging to convert three C-3's for the American-South African Line. The changes were similar to the American President conversions, but with passenger capacity increased to 116 and increased public rooms.

In the summer of 1939 a conversion was contemplated for the U.S. Lines involving four C-3's on the run to London. Accommodation for 165 passengers, 53,000 cub. ft. of refrigeration space, 537,000 cub. ft. of dry cargo capacity and deadweight of 8200 tons was expected.



Main engine of a Victory (Hannibal)



Upper level showing main turbine, looking Port to Starboard on the Frederick Victory.

The most extensive conversions contemplated were for the Moore-McCormack Lines, embracing 216 passengers and with superior accommodations, such as compartments amounting to staterooms. Similar conversions were contemplated for the Mississippi Shipping Company.

These C-3 conversion possibilities illustrate the extreme in flexibility which may be obtained from a general design which has a basic sustained speed of 16½ knots and an initial cubic capacity of 730,000 feet and a deadweight of 12,000 tons.

In considering post-war plans there is a general expectation that trade between America and the countries across the Pacific will reach unprecedented volume. In anticipation of this the Commission is building on the West Coast three vessels of P-2 design for the American President Lines.

The P-2 type is the result of a design started by the Commission before the war for passenger vessels intended for intermediate services. During 1941, when the Country's resources in ships for military use were being investigated, it became apparent that should the United States be forced to go to war at any distance from our shores, there would be a serious deficiency in vessels available for transport duty. Therefore, the P-2 design was pushed, so that by the time we were attacked the Commission was able to negotiate their immediate construction, knowing that when these vessels ended their war service their post-war use would be valuable.

The P-2's being built are designated as the P2-R3, with turbo-electric propulsion and a designed speed of 19½ knots from a s.h.p. of 18,000. They are 590 ft. long with a draft of 30 feet, and the original design

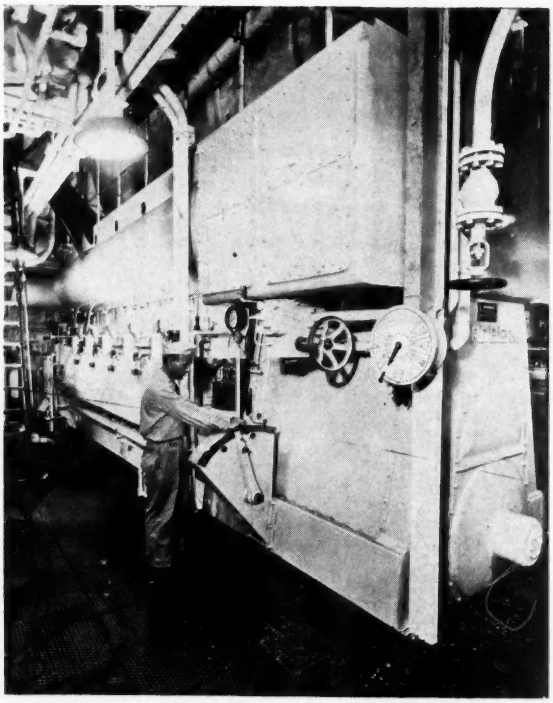
provided for accommodation for 550 passengers.

Inasmuch as services on Pacific routes require ship facilities different from most other trades, the P-2's being built are undergoing conversions to suit the route involved. The longer distances of the Pacific require more fuel tankage and radius of operation than most other lines. These vessels will carry three classes of passengers, with a good proportion of the third class having open berthing as has been customary on the trans-Pacific run.

Another large type of vessel built as a result of war demands is the C-4, a ship built on the C-design, but specifically for a troop carrier. Its characteristics, as may be noted from the foregoing table, give it greater length, draft and power than the C-3, and its design may give it a post-war use of some consequence. Ten or more will be available for whatever use develops for them.

It can readily be seen that many constructive changes in shipbuilding were brought about by the war. The development exciting the most wonder was the Liberty programme, which provided some 2700 cargo vessels at the most critical time in the world's history. Disposition of this great quantity of tonnage is one of the problems faced by the United States. Out of it came the "know-how" to build fast ships rapidly, and the knowledge gained may be an excellent deterrent to future aggressors.

The net result of the Commission's experience in the war—and we hope we will be sustained by the nation, the Congress and the industry—is that shipping must be kept on an even keel. The United States has regained its once lost maritime stature in full measure. To retain our position requires a full blown resistance to dissipation of our shipbuilding talents and skill in the maritime sciences.



Nordberg main propulsion Diesel engine—Starboard side looking aft—on a C1-M-AV1.

DEVELOPMENT OF HIGH TEMPERATURE ALLOYS IN THE UNITED STATES.

EARLY in the war the armed services sought alloys which would, at temperatures of 2100—1500 deg. F., have strength previously unheard of in this temperature range. Stimulated by the official demands many producers of alloys and many laboratories went to work to develop new metals. The principle use in view was for components of gas turbines. First came the turbo supercharger and later gas turbine engines for jet propelled aeroplanes and in development are gas turbines for prime movers for locomotives, ships or central generating stations.

Since most of the emphasis throughout the war was placed on the requirements of aeroplane engines, the design engineers sought alloys that would support very high unit loads for relatively short periods. The life of an aircraft engine in military service was usually very short and the engineers were satisfied with a useful life, in the metal components, of a few hundred hours. In some cases, one hundred hours was considered sufficient; in other cases, three hundred or a thousand hours might be required.

Acceptance tests were based on what is usually called "stress rupture" data. These values indicate the stress an alloy will sustain without fracture for a definite number of hours at a definite temperature. Due to the influence of the aeroplane engine, stress-rupture data have been usually reported for 100, 300, 500 or 1000 hours. Most of the reported values have been either for 100 or 1000 hours. In the case of design for engines that must have a longer useful life, extrapolation has beeen resorted to and a form of relaxation test has been used.

In the early work it was thought that engines which would operate at 1200 deg. F. would be satisfactory, but later this was changed and research aimed at developing alloys to have high stress-rupture values at 1500 deg. F.

The better alloys available in 1941, were nickel chromium iron or nickel chromium alloys with little or no addition of other elements. These alloys in 1941 offered values of 30,000 to 50,000 lbs. per sq. in. stress for rupture in 100 hours and 20,000 to 40,000 for rupture in 1000 hours, both at 1200 deg. F. These alloys were relatively useless above 1200 deg. F.

A large number of alloys were worked on by many different sponsors and testing laboratories in a coordinated programme. The first attempts were made to increase the high temperature strength by small additions of one or more or combinations of the hardening elements; namely, tungsten, molybdenum, columbium titanium, nitrogen and carbon. The base alloys to which the hardening elements were added usually contained 15 per cent, 20 per cent or 25 per cent of chromium, 15 to 30 per cent of nickel and the balance iron. The carbon levels explored were either low (less than ·10 per cent C.) or medium (about ·50 per cent C.). The hardening elements were tried in a large number of amounts and combinations. These alloys had higher rupture strength than the simple alloys and pushed the values for 1200 deg. F. up to the vicinity of 55,000 lbs. per sq. in. for 100 hours and 45,000 for 1000 hours. The 1500 deg. F. stress-rupture values were raised to 20,000 lbs. per sq. in. for 100 hours and to 10,000 for 1000 hours.

A group of nickel base alloys having good properties

at 1500 deg. F. have been developed. These contain no cobalt and no tungsten, but are straight nickel chromium alloys with incidental iron or negligible iron and are hardened by small amounts of addition elements.

The best alloys of this group show very high rupture values of 60,000 lbs. per sq. in. for 100 hours at 1200 deg. F. and over 55,000 for 1000 hours. At 1350 deg. F. these alloys will sustain stresses of 48,000 and 38,000 lbs. per sq. in. for 100 and 1000 hours respectively. At 1500 deg. F. the stress rupture values are 30,000 lbs. per sq. in. for 100 hours and 16,000 to 18,000 for 1000 hours.

Other investigators have added cobalt to the nickel chromium base with excellent results. The base alloys were altered to contain 20 to 40 per cent of cobalt in addition to the original 15 to 25 per cent of chromium and 15 to 30 per cent of nickel. The modified base alloys were again hardened with additions of the elements W, Mo, Cb, Ti, N_2, and C in varied proportions. The addition of cobalt raised the stress rupture values up to levels equivalent to those just cited for the nickel base alloys at 1500 deg. F. At 1350 deg. F. and 1200 deg. F. these alloys are apparently not as good as the nickel base alloy.

The foregoing refers to wrought alloys capable of being produced in large melts, forged and rolled. Development of cast alloys has indicated as good or better properties but this is limited to small size parts.

All or most of the alloys currently under development, respond to heat treatment. The nickel base alloys are always heat treated for applications at temperatures of 1000 deg. F. or higher.

The 1500 deg. F. strength of the alloys now available is at least twice that of the best alloys known to engineers and metallurgists before the war. The whole development of these "1500 deg. F. alloys" has made it possible to design gas turbines to operate at temperatures from 1200 to 1400 deg. F. or even higher. Because of the high theoretical efficiencies of the gas turbine operating at these temperatures, great potential opportunities are foreseen and this development in alloys may prove one of the most important metallurgical advances made during the war.

THERMOANALYSIS IN METAL CUTTING.

By A. O. SCHMIDT, Sc.D., Research Engineer in Charge of Metal Cutting Research, Kearney & Trecker Corporation, Milwaukee, Wisconsin.

A MACHINE tool is the inverse of a heat engine. While heat in some form is transformed into mechanical power in a heat engine, a machine tool is supplied with mechanical power which generates heat. A machining operation removes metal and thereby produces the desired result. As this cutting action becomes more efficient, less heat is generated in the chips, workpiece and tool. Minimum heat generation is synonymous with minimum power consumption.

Marked increases in production have been achieved as a result of improved cutting tool materials, tool design, higher operating feeds and speeds, workpieces designed and heat treated to facilitate machining, as well as increased rigidity and power in machine tools. The technique of machining steel with cemented carbides has advanced rapidly. It is not surprising, therefore, that contradictory theories concerning this technique are frequently advanced from various quarters. To many authors on the subject, phenomenal cutting speeds seem to be the ultimate answer to the problem of the most efficient method of machining steel. Results of numerous careful investigations, however, do not indicate that extremely high speeds, in excess of 1000 feet per min., will be advantageous.(1)*

The first law of thermodynamics can be applied to any metal cutting operation, "When work is transformed into heat, or heat into work, the quantity of work is the mechanical equivalent of the quantity of heat." In machining operations, the calorimetric method has been used to determine power consumption at the tool. In a recent study of the forces in a drilling operation (2) a calorimeter was mounted on a dynamometer, Fig. 1. Power values obtained from this set-up, with either device, were in close agreement, within 1 to 3 per cent. Various metals were machined at different feeds and speeds. Since the individual tests were of only a few seconds duration, no corrections for heat losses were made because they did not influence results to any appreciable degree.

In computing the change of heat in the calorimeter the following formula can be used:

$$dQ = W\, c_m\, dT$$

where dQ = change of heat in the calorimeter
W = weight of calorimeter
c_m = mean specific heat of calorimeter
dT = change of temperature

The quantity of heat which the body W absorbs when heated from room temperature to a higher temperature is

$$Q = W \int_{T}^{T_h} c_m\, dT$$

where T_h = final calorimeter temperature
T = initial calorimeter temperature

Since the mean specific heat, c_m, can be considered constant in this case and all parts of the calorimeter as having obtained the same temperature,

$$Q = W\, c_m\, (T_h - T)$$

In investigating radial rake angles in high-speed milling, a special calorimetric apparatus has been developed which permits determination of the relationships between cutting speeds, feeds, tool angles, and workpiece materials (3). The power required by the tool can be measured by determining the amount of heat in the chips with the calorimeter. There is no more reliable indication of the actual power consumption since most of the heat generated in a metal cutting operation

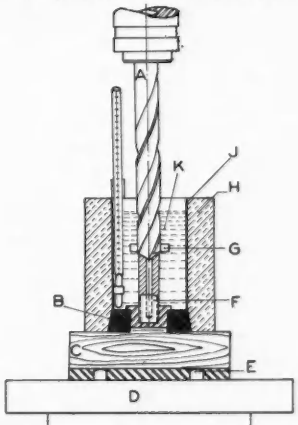


Fig. 1. Calorimetric apparatus for drilling tests mounted on a dynamometer for registering torque and thrust simultaneously.

(a) Drill (b) Rubber grommet (c) Woodblock (d) Dynamometer for torque and thrust (e) Centring pins (f) Test bar (g) Blades on drill for agitation (h) Felt insulation (j) Container (k) Water (50 cc.).

* Number in parenthesis refer to the bibliography at the end of the article.

is contained in the chips. Tests conducted for over two years produced very consistent results which could be duplicated at any time. Discrepancies caused by varying efficiency of the machine tool drive motor and lubrication and friction factors in gears and bearings are eliminated. The calorimeter also has advantages over a dynamometer in that no delicate or complicated details are involved and the apparatus itself is not affected by vibration at high cutting speeds.

A quantity of distilled water is employed as the medium for measuring the amount of heat generated by a combination of metallic friction and deformation during the cutting operations which are run without cutting fluids. The change of temperature of the water into which the chips fall is measured with a thermometer. To obtain correct chip temperature and power values, the water equivalent of the calorimeter and chips must be determined. Cutting time for each test should be as short as possible in order to minimize the heat losses. At the start of a test, water and equipment should be held constant at room temperature.

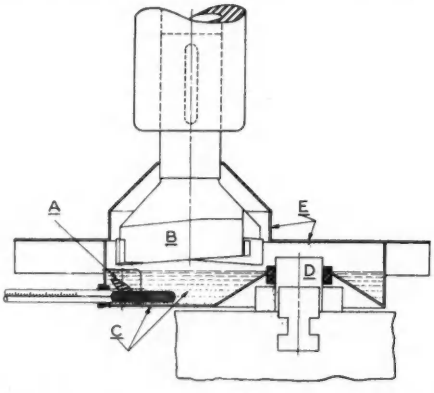


Fig. 2. **Calorimetric apparatus and tool in working position for milling tests.**
(a) Agitator (b) 3" cutter (c) Container with 150 cc. of distilled water (d) 1" diam. test bar (e) Cover.

Arrangement and design of the calorimeter is shown in Fig. 2. Two-bladed cutters were used in the tests which were run on a Milwaukee 2K vertical milling machine[4]. Cutters were tested, each with different radial rake angles, including 30, 15, 6 deg. positive, 0 deg., and 6, 12, 20, 30 deg. negative. Test bars of 0·55 per cent C steel, Bhn 205, and 1 in. diam. were held in a three-jaw chuck which was secured to the table so that its centreline coincided with that of the cutter in the direction of table travel.

DERIVATIONS OF CALORIMETRIC FORMULÆ

In each test a 1 in. diam. steel bar is milled to a depth of 0·125 in., 0·0982 cu. in. or 0·0278 lb. of metal being removed. Assuming the specific heat of steel as 0·110, the total water equivalent of the calorimeter, 150 c.c. of water, and the chips is 0·3600 lb., which value is used in the following computations.

The net horse-power expended in the chips is the mechanical equivalent of the heat increase in the calorimeter divided by the cutting time. Therefore :

$$\text{Net h.p.} = \frac{(\Delta T)\ (\text{total water equivalent})}{(\text{Cutting time, min.})\ (42{\cdot}44\ \text{B.T.U./min.})}$$

where

ΔT = Calorimeter temperature rise, deg. F.

1 h.p. = 42·44 B.T.U./min.

Since the length of cut is 1 in., the cutting time may be expressed as the reciprocal of the feed rate in inches per minute or 1/F. Then

$$\text{Net h.p.} = \frac{(\Delta T)\ (0{\cdot}3600)}{(1/\text{F})\ (42{\cdot}44)}$$

Solving this equation, with ΔT as the independent variable, for each feed used

$$\text{Net h.p.} = K_{\text{F}}\Delta T \qquad (1)$$

where $K_{\text{F}} = \dfrac{0{\cdot}3600}{(1/\text{F})\ (42{\cdot}44)}$

a constant depending upon the rate of feed in inches per minute.

The horsepower needed to mill 1 cu. in. of metal per min. is computed as follows :

$$\text{h.p. per cu. in. per min.} = \frac{\text{Net h.p.}}{\dfrac{\text{Volume metal removed (cu. in.)}}{\text{Cutting time (min.)}}}$$

Substituting expressions and values previously determined :

$$\text{h.p./cu. in./min.} = \frac{\dfrac{(\Delta T)\ (0{\cdot}3600)}{(1/F)\ (42{\cdot}44)}}{\dfrac{0{\cdot}0982}{(1/F)}} = \frac{(\Delta T)\ (0{\cdot}3600)}{(42{\cdot}44)\ (0{\cdot}0982)}$$

$$\text{h.p./cu. in./min.} = 0{\cdot}0864\Delta T \qquad (2)$$

Maximum average chip temperature rise, ΔT_{c}, can be found by two methods. In either case, the procedure of thermal balance commonly carried out in calorimetric tests is used. One method of determining the relation between calorimeter and chip temperatures in these tests, assuming 0·110 as the constant specific heat of steel, is as follows :

(ΔT_{c}) (chip wt.) (sp. ht.) = (ΔT) (water equivalent of calorimeter, water, and chips)

$(\Delta T_{\text{c}})\ (0{\cdot}0278)\ (0{\cdot}110) = (\Delta T)\ (0{\cdot}3600)$

$$\Delta T_{\text{c}} = \frac{(\Delta T)\ (0{\cdot}3600)}{(0{\cdot}0278)\ (0{\cdot}110)}$$

$$\Delta T_{\text{c}} = 117{\cdot}724\Delta T \qquad (3)$$

The values obtained with this formula exceed the actual maximum average chip temperature rise, in many instances by more than 100 deg. F., because the specific heat of steel was assumed to be constant in the derivation. Since data on the variation with temperature of the specific heat of 0·55 per cent C. steel is not available, the above formula will give approximations of the chip temperature rise.

To determine the maximum average chip temperature rise with a greater degree of accuracy, the initial equation in the derivation of equation (3) can be used :

$$\Delta T_{\text{c}} = \frac{(0{\cdot}3600)\ (\Delta T)}{(0{\cdot}0278)\ (\text{sp. ht.})}$$

Actually, the specific heat of steel increases with the rise in temperature, and the formula should be expressed as :

$$\Delta T_{\text{c}} = \frac{(12{\cdot}95)\ (\Delta T)}{\text{sp. ht}_{\text{c}}} \qquad (4)$$

in which the specific heat varies with the chip temperature.

Chip temperatures were assumed and the corresponding specific heat values for gamma iron were obtained from the A.S.M. Handbook*. A sufficient

* A.S.M. Handbook, 1939 edition, table vi, p. 431.

number of calorimeter temperature rise values were computed with equation (4), using the gamma iron data, to plot a curve which represented the maximum average chip temperature rise. Thus the true maximum average chip temperature rise was not determined by the formula, but a corrected temperature value was taken from the curve or a table based on that curve. Although the latter procedure does not give absolutely accurate values, it is a much better approximation of the true chip temperature rise than that obtained with the former method.

TOOL FORCES, CHIP, WORKPIECE, AND TOOL TEMPERATURES.

From the net horsepower of the cutter, as determined by the calorimeter, the tool forces were computed for the different rake angles with the formula

$$\text{h.p.} = \frac{F \times V}{33000} \quad \text{or} \quad F = \frac{\text{h.p.} \times 33000}{V}$$

where V = cutting speed.

This force, F, is the resultant of several component forces and it can be seen in Fig. 3, that F increases with

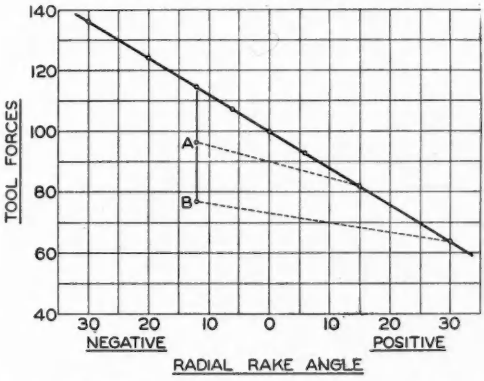


Fig. 3. Tool forces in relation to radial rake angles on a milling cutter.

Forces on 0 deg. rake cutter taken as 100. (Points indicated at (A) and (B) represent relative tool forces on cutters which had a negative primary radial rake angle of 12 deg. and a positive secondary radial rake angle of (A) 15 deg. or (B) 30 deg.

the negative radial rake angle and decreases with the positive radial rake angle. It also shows how much the tool forces on a cutter with 12 deg. negative primary radial rake angle are reduced by the application of a positive secondary radial rake angle of 15 or 30 deg., Fig. 4.

It was found that the cutting force for a particular radial rake angle and chip cross section has substantially the same value at any cutting speed.

At a cutting speed of 300 feet/min., the tool forces were not different from those at 600 or 1200 feet/min. Since the maximum volume of metal removed with any test cutter was 0·3 cu. in. per cutting tip, the cutters would be considered sharp. Therefore, any error introduced by a change in the cutting edge could be disregarded entirely. However, when cutting at 600 feet/min., twice as much metal is removed per unit time as at 300 feet/min. and, consequently, the power required for cutting is doubled. In computing the chip temperature with the formula given, the same value was obtained for both cutting speeds, Fig. 5. Although twice as much work was done per unit time when cutting at a speed of 600 feet/min. as compared with 300 feet/min., the temperature of the chips remained the same because the work was done in removing twice the amount of metal. This means there is twice as much chip material to carry away twice as much heat. (The

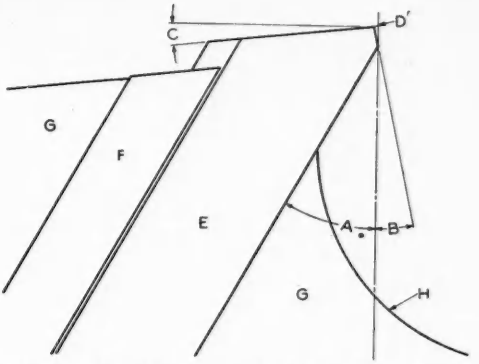


Fig. 4. Schematic diagram of milling cutter tooth with 12-deg. negative primary radial rake and positive secondary radial rake angle.

(A) Positive secondary radial rake angle (B) Negative primary radial rake angle (C) Peripheral clearance angle (D) Cutting edge (E) Inserted solid cemented carbide blade (F) Hardened wedge (G) Face mill body (H) Chip clearance surface.

amount of heat per unit weight of chips remains constant.)

Even though heat producing work must inevitably be done in metal cutting, it is impossible to remove metal at extremely low speeds with a relatively low temperature rise in the chip ([5]). This is possible because the chip is separated slowly, and the heat in the chip is given a chance to flow into the tool and the workpiece. At higher speeds the amount of work done is proportional to the increased cutting speed, and most of the heat developed is carried away with the chip because of the short time the chip is in contact with the workpiece and tool.

The average chip temperature measured at higher cutting speeds is more uniform because there is less chance for the heat to travel into the tool and the workpiece. As soon as the temperature at the cutting edge corresponds to that in the chip, there is no further heat flow from the chip into the tool. The greater amount of work which is done per unit time at higher cutting speeds and the resulting greater amount of heat is carried by a correspondingly larger weight of chips.

When the cutting speed is increased, the tool will have to do a proportionately greater amount of work. This results in a temperature increase in the tool material. The heat will not be uniform in the tool, but most intense near the point at which the cutting takes

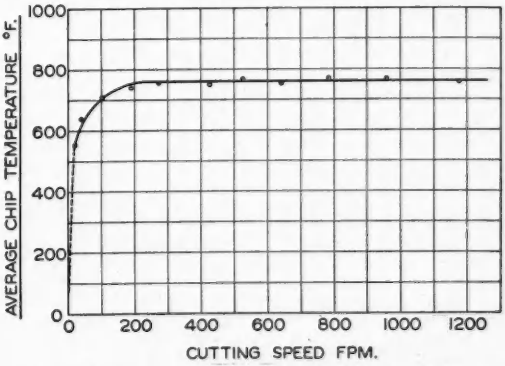


Fig. 5. Average temperature of steel chips in relation to cutting speed.

(Feed per tooth 0·008 in., cutter with 6 deg. neg. radial rake angle. The dotted line indicates estimated temperature values at cutting speeds below 25 feet/min.)

place. The zone near the cutting edge will reach the highest temperature and consequently break down first.

The heat of the tool is of greatest importance because it is the accumulation and concentration of intense heat at the cutting edge of the tool which hastens failure. Comparing tool life with cutting speed, as brought out in many reports ([6]), it is evident that the amount of metal removed before tool failure, will generally be inversely proportional to the cutting speed when the chip cross section is kept constant. This happens despite the fact that the chip temperature will remain substantially the same. Assuming an ideal case in which the tool does not wear and thus change the cutting forces, the same volume of tool metal has to dissipate twice the amount of heat per unit time when the cutting speed is doubled. For this reason, a tool will break down faster at higher cutting speeds, and remove a smaller volume of metal than at a lower cutting speed. There is only a small zone including the cutting edge of the tool which will have a high heat increase with an increase in cutting speed. It is in this zone that most of the friction between the chip and the tool occurs.

High cutting speeds, from 1000 to 3500 surface feet/min., have been reported and frequently recommended for steel milling operations. Behind these recommendations is the belief that definite advantages can be realized from extremely high cutting speeds. To ascertain the effect of cutting speed upon the cemented carbide cutting edge another series of milling tests was made at speeds from 130 to 3280 feet/min. with the same feed per tooth maintained at each speed ([1]). The results confirmed that the friction between the chip and the blade face and the heat generated by the friction, both of which are concentrated in the zone immediately around the cutting edge, cause a greater degree of tool wear at high cutting speeds than at low speeds with the same volume of metal being removed at each speed.

In the several thousand steel milling experiments which were conducted with the calorimetric test equipment, the surface temperature of the workpiece was measured before and after each cut with an Alnor low range thermocouple.

The temperature of the workpiece is affected chiefly by its size, heat conductivity, and specific heat. Other factors which also influence the workpiece temperature include cutting speed, cross section of chips, tool design, and wear at the cutting edge. All these must be taken into consideration.

However, if all conditions except cutting speed are kept constant, the following can be stated with regard to the chips, tool, and workpiece :

The temperature of chips of uniform cross section remains approximately the same in the high range of cutting speeds.

The temperature at the cutting edge of a tool increases with the cutting speed.

The temperature of the workpiece is lower at the higher cutting speeds.

From the calorimetric power analysis and cutter life tests the following points in particular have been established :

Power required at the cutting edge is higher for the negative-radial-rake-angle cutters than for cutters with positive radial rake angles. This holds true for conventional cutting speeds as well as for higher cutting speeds up to 1180 feet/min.

Cutters with negative radial rake angles will stand up longer than positive-radial-rake-angle cutters under identical conditions.

At high speeds, wear and failure at the cutting edge of a positive-radial-rake-angle cutter will soon increase its power consumption above that of a cutter with negative radial rake angles.

A cutter with a 15 or 30 deg. positive secondary radial rake angle with a negative primary radial rake angle at the cutting edge 1 to 2 times the width of feed per tooth, was found to be most effective since it combined the increased strength of the cutting edge afforded by negative radial rake angles with the lower power requirement of the cutter with positive radial rake angles.

Fig. 6. **Milling cutter 10 in. diam. with 12 inserted blades at 15-deg. positive secondary radial rake angle with negative primary radial rake angle at cutting edge.**
By grinding different radial rake angles, see (B) Fig. 4, at the cutting edge, the same cutter can be used on other materials, e.g. aluminium, cast iron, nickel alloys.

Fig. 6 shows a face milling cutter which is designed according to the principles arrived at in the calorimetric studies. The solid cemented carbide blades are set at a 15 deg. positive radial rake angle and are provided with a negative radial rake face 0·020 in. wide at the cutting edge. The wedge which holds the cutting blade in place is positioned in the back in order to provide uninterrupted chip accommodation space in front of the blade. The blades can easily be exchanged or reset when necessary and in regrinding the cutter, very little carbide material has to be removed. The arrangement of the two radial rake angles on the same tooth will permit simple and complete removal of all wear marks by regrinding. This milling cutter has been tried in long run production tests on aircraft parts made of high strength alloy steels and has proven superior in number of workpieces per grind. It cut at feeds and depths of cut which stalled the same milling machine when ordinary negative rake angles cutters were used. The lighter temper colour, shape, and deformation of the chips as well as lower wattmeter readings demonstrated a better cutting action which caused less pressure, vibration, and deflection in the workpiece and machine tool members. Calorimetric measurements confirmed that combined-angle cutters require less power at the cutting edge than negative-angle cutters under identical conditions.

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TECHNICAL NEWS

Announcements in this section include News relating to British Firms, and on Equipment produced by British Manufacturers.
Available literature may be secured by addressing a request to the advertising department of "The Engineers' Digest," or by writing direct to the manufacturer and mentioning "The Engineers' Digest" as a source.

- ✦ NEW EQUIPMENT
- ✦ BOOKS AND CATALOGUES
- ✦ BUSINESS CHANGES
- ✦ PERSONAL
- ✦ NOTES

PERSONAL.

Mr. N. Corcoran, B.A., B.Sc., M.Sc.Tech., A.Inst.P., is leaving his present radar research post with the Ministry of Supply to take up an appointment as lecturer in physics at Stockport College for Further Education, on January 1st, 1946. Before joining the Ministry of Supply in 1941 Mr. Corcoran was for some years responsible for illuminating engineering in the Manchester office of Metropolitan-Vickers.

Mr. W. S. Edwards, M.I.Mech.E., M.I.Loco.E., has been made a Vice-President of the Institution of Locomotive Engineers. He has been a Member of Council of the Institution for 25 years. Mr. Edwards is Managing Director of W. G. Bagnall Limited, and of Cowlishaw Walker Engineering Co. Ltd. He is President of the Engineering Employers Association, North Staffordshire.

Mr. A. Fage, A.R.C.S., D.I.C., F.R.Ae.S., F.R.S., has been appointed Superintendent of the Aerodynamics Division of the National Physical Laboratory, with effect from January 1st, 1946, to fill the vacancy caused by the resignation of **Mr. E. F. Relf,** A.R.C.S., F.R.Ae.S., F.R.S., who is taking up the post of Principal of the College of Aeronautics. Mr. Fage has been a member of the staff of the National Physical Laboratory since 1914.

Sir N. V. Kipping having resigned from the Board of Trade in order to take up his appointment as Director General of the Federation of British Industries, **Mr. G. Calder** succeeds him in charge of the Regional Organisation of the Board of Trade, and will also be responsible for the administration of the Distribution of Industry Act, 1945, and cognate matters, at present dealt with by **Sir Philip Warter,** who will continue to assist the Board in an advisory and executive capacity, especially in connection with Trading Estate Companies and the disposal of Government factories.

Mr. E. S. Little has been appointed Secretary of the British Thomson-Houston Co. Ltd. Mr. Little, who is a Director of the company, will combine the duties of Secretary with his existing duties as Comptroller.

Mr. A. P. Newall, Chairman and Managing Director of Messrs. A. P. Newall & Co. Ltd., Woodside Engineering Works, Possilpark, Glasgow, has been presented with an illuminated address and silver tea-tray, as an acknowledgment of his distinguished contribution to the Nut and Bolt Industry over many years. The presentation was made by **Major C. R. Dibben,** Independent Chairman of the various British Bolt and Nut Manufacturers' Associations, and he was accompanied by **Mr. G. F. V. Richards,** Deputy Chairman of the Black Bolt and Nut Manufacturers' Association of Great Britain.

Mr. F. H. Rolt, M.B.E., B.Sc., A.C.G.I., M.I.Mech.E., has been appointed Superintendent of the Metrology Division of the National Physical Laboratory, with effect from April 1st, 1946, on the retirement from that post of **Mr. J. E. Sears,** C.B.E., M.A., M.I.Mech.E. Mr. Rolt has been a member of the staff of the National Physical Laboratory since 1912, but during the war his services were lent to the Ministry of Supply, where he was Director of Jigs, Tools and Gauges.

NEW LITERATURE.

BRUCE PEEBLES WAR-TIME ACTIVITIES.

"ACHIEVEMENTS 1939-1945" is the title of a 32-page booklet issued by Bruce Peebles & Co. Ltd., to indicate the war-time accomplishments of the company. The publication is in two parts, the first gives a brief but informative survey of the company's activities and achievements in war production, which covered a very wide field in many categories of an electrical and non-electrical character. Besides all classes of electrical plant—generators, converters, transformers, motors—for essential services, large numbers of machines of special design were supplied for all classes of naval and merchant ships, and for the military and air services. The development and manufacture of the multiple rocket projector for the air war; the production of pilot models and large scale production of new devices to combat enemy action at sea; the manufacture in record time of pontoons for "Mulberry," these and many other war-winning contributions made by Bruce Peebles are described and illustrated in the booklet. The company has already largely completed its preparations to meet the vast demands of peace-time reconstruction and development at Home and abroad, and part two of the booklet deals with the company's leading lines of manufactures for peace-time purposes, notably, rotating electrical machinery, transformers, rectifiers, and welded steel structures.

SCIENTIFIC RESEARCH.

AN important step in the intensification of scientific research to maintain and enhance the supremacy of British Industry is marked by the announcement by Standard Telephones and Cables Limited of the formation of a central laboratory organisation to undertake long-term research and development in the telecommunication, electronics and allied fields. The new laboratories, to be known as Standard Telecommunication Laboratories Limited, will be housed at Progress Way, Great Cambridge Road, Enfield, pending the erection of suitable permanent premises.

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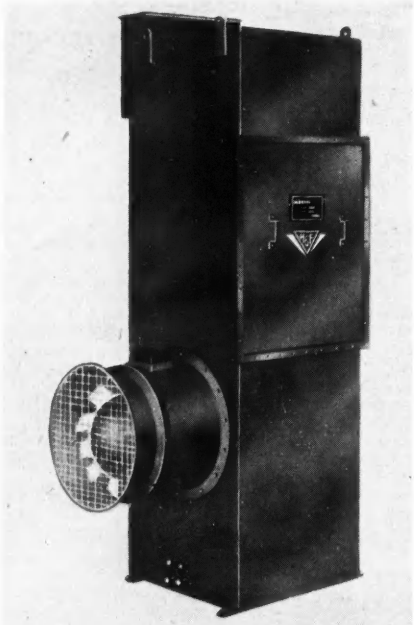

NEW EQUIPMENT

THE HEENAN P TYPE COOLER.

Many industrial mechanisms and processes liberate heat which must be removed continually. These include internal combustion engines which require a flow of cooling water through their jackets to carry away the heat of combustion; condensers of refrigerating plants; air compressors in which the heat of compression must be removed; engines and dynamometers in test shops; platen presses; welding plants; large printing machinery; quenching tanks in heat treatment shops; and many others.

It is often inconvenient to draw water continuously from town mains or other supply for such cooling purposes, either because of expense or because the water may be hard or scarce. In many instances, danger to plant would follow a failure of the water supply and it is desirable to have some system which makes the plant less dependent upon outside source of water.

For such reasons it is usual to install a cooling plant which constantly re-cools the water in a circulation. One of these is the Heenan Cooler, which is of the forced-draught pattern and of all-metal construction.

The first Heenan Cooler was supplied in 1911: the well-known V. type was marketed in 1920, and its successor the T. type in 1937. The latter was supplied in large numbers before and during the war, but in spite of the difficulties of the times research was continued and an improved model, Type P., is now introduced.

The Heenan P. type Cooler, as illustrated, follows substantially the same lines as the previous models, but in it the makers claim reduced first cost, decreased power consumption, and greater ease of maintenance. The most obvious differences are the suppression of the centrifugal fan for providing the cooling air, in favour of a high-efficiency axial-flow fan; sizes and construction of the cooling screens; and means of access to the distribution troughs.

To obtain minimum compactness and most economical design, the problems to be solved were those of providing the most efficient cooling surface for the interchange of heat between water and air, and the utilisation of every pound of air to the best advantage, and it is an interesting fact that, at normal water temperatures, the air leaves the P. type Cooler having done some 90 per cent of the work theoretically possible in extracting heat.

The ecomomies effected by such coolers are not always appreciated. Frequently, the cooler is installed on technical grounds, but it nevertheless constitutes a very profitable investment. After allowing for upkeep, maintenance and depreciation, it is not unknown for a Cooler applied to a stationary diesel engine, for example, to recover its first cost in a few months.

The water savings are large and on diesel engine work are at least 95 per cent of the mains water usually wasted. Should the water supply be hard, or of corrosive nature, saving is also effected in the cost of water treatment plant.

In the application of the Cooler to quenching oil used in heat treatment shops, the air cools the oil directly. As the use of water in this case is entirely obviated, the water costs are saved; the cost of current for driving the fan is usually small in comparison, and there is no water to contaminate the oil.

In special cases where the cooling fluid must be kept in a closed circuit, a tubular heat-exchanger is employed, and the water of the secondary circuit is continuously re-cooled in the Cooler.

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RECENT DEVELOPMENTS IN THE AXIAL-FLOW BLOWER.

By JAMES G. SAWYER, Chief Engineer, Buffalo Turbine Corp. (Formerly of Curtiss-Wright Corp.).

STATUS OF THE AXIAL-FLOW BLOWER, 1938.

FOR a considerable period prior to World War II., comparatively little development activity was apparent in the field of axial-flow blowers. The now popular airfoil type fan had been known for some years, having been successfully applied to the gas turbine compressor by Brown-Boveri a number of years before. The treatment of the axial-flow fan by Curt Keller[1] was becoming the standard text on axial-flow fan design. A fan of this type is shown in Fig. 1. Fan manufacturers had one by one been developing commercial lines of these fans.

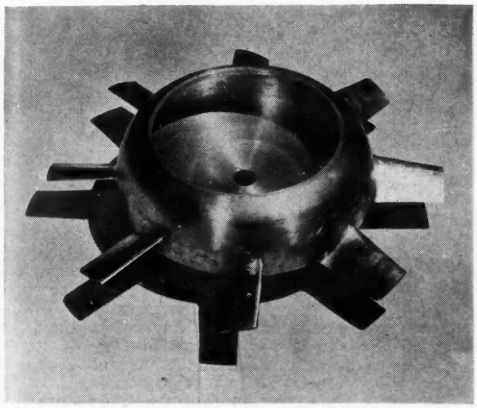

Fig. 1. **Conventional Airfoil Fan. Courtesy—Curtiss-Wright Corp.**

THE AIRFOIL THEORY.

The airfoil theory of fan design constitutes an application of the aerodynamic airfoil to the fan. The design calculations relate the fan performance to the airfoil lift coefficient used in aeroplane design. This method has lead to designs of unusually high efficiency, but very moderate pressures.

These fans correspond to backward curved radial flow fans, both in design and performance. Both types have relatively few backward curved blades, turn the air through relatively small angles and have low pressure coefficients. Also, both types have sharply declining pressure curves with increasing flows.

The Keller work investigated at length the maximum pressure coefficient obtainable with this type of design. It was discovered that this design method would not yield pressure coefficients greater than $\Psi = \cdot 7$, where :

$$\Psi = \Delta p / \tfrac{1}{2} \rho U^2_{tip}$$

Ψ = pressure coefficient
Δp = fan pressure rise
ρ = air mass density
U_{tip} = fan tip peripheral speed.

Most radial flow blowers have pressure coefficients of the order of 1·5, and some as high as 2·0.

Local flow around fan blades was investigated by lattice tests, conducted on a specially constructed wind tunnel. Stalling was found to occur when the blades were sufficiently closely spaced to develop pressure coefficients greater than 0·7. The limiting spacing was found to be at a chord/pitch ratio of the order of unity.

THE WATTENDORF FAN THEORY.

Shortly before the war, Dr. Frank Wattendorf, of Dayton, Ohio, had been doing some very significant work on axial-flow fans. His paper, " The Ideal Performance of Curved-Lattice Fans,"[2] revealed how he had developed, in theory and test, fans with chord/pitch ratios substantially greater than Keller's, and pressure coefficients correspondingly greater. His theory recognizes the principle that in order to obtain greater pressure coefficients, it is necessary to turn the fluid through greater angles. Treating the runner flow problem on the basis of the desired energy input, the required flow directions are determined. Here use is made of the simplified form of Euler's turbine equation :

$$\Delta p = \rho U \Delta C_u$$

where ΔC_u is the change in rotational velocity within the runner.

Wattendorf, bending the conventional airfoil by a method of conformal transformation, lines up the leading and trailing edges with the desired flow directions A number of these units were constructed, and were highly successful.

Mr. J. F. Hagen, of the B. F. Sturtevant Company, revealed in the publication, " Centrifugal and Propeller Fans,"[3] a method of axial-flow design relating the blade angels directly to the fluid vectors. Using a simplified method of bending the blade, Mr. Hagen had for some time been employing the principle.

The Wattendorf paper[2] points out the significant fact that the slope of the pressure-flow curve is uniquely related to the design pressure coefficient. He developes in theory, ideal performance curves indicating axial-flow fans may develop pressure coefficients as high as two and three with distinctly rising pressure curves. This is quite contrary to what has been the popular concept of the axial-flow fan.

THE CONSTANT PRESSURE BLOWER.

In August, 1939, a German engineering society publication[4] revealed the existance of a new type of blower known as the constant-pressure blower. The article deals with the constant-pressure design theory. This theory proposes, by eliminating pressure gradients within the runner, to reduce the stalling tendencies which have hitherto limited the axial-flow fan.

That which seems most significant to the author is not the Constant Pressure principle, but the fact that the paper presumes of the reader, prior knowledge of what it calls the Stream Filament principle. In the stream filament principle it is explained, for closely spaced blades, the flow within the runner is assumed to be substantially parallel to the blade surfaces. This, of course, is the same basic assumption made by Wattendorf and Hagen. Here again, Euler's equation is applied to determine the desired flow direction and the blade angles are subsequently determined.

The concept of constant pressure within the runner is claimed to be an invention of a Mr. Schicht. He proposes, by maintaining the relative velocity W constant, to eliminate adverse pressure gradients. In the conventional fan, as the oblique flow is directed axially, W is reduced, thus creating a positive pressure gradient. The passages are in effect, curved diffusers.

Schicht designs the blade with a reducing radial height so as to maintain the passage area and thus W constant. A wheel with decreasing blade height is shown in Fig. 2. The desired energy is in the fluid, but since there is no increase in static pressure, the energy is entirely in the kinetic or velocity form. It is necessary to reduce the high axial velocity in an annular diffuser behind the fan to develop the required static

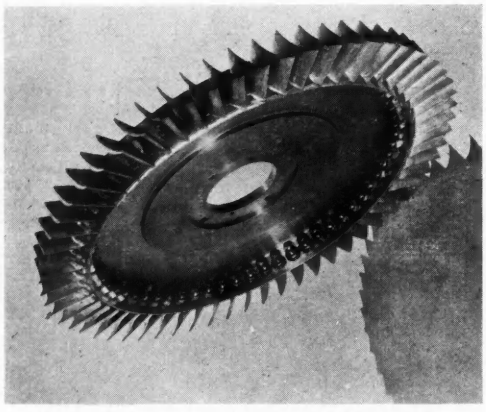

Fig. 2. **Partially "Schichted" Turbine Fan. Courtesy—Curtiss-Wright Corp.**

pressure. In other words, diffusion is not eliminated but only delayed.

The fundamental assumption of the Schicht theory, as set forth in the German publication,[4] is that high static pressures cannot be efficiently developed within the runner, but can be so developed within an after diffuser. It states this is true only when the static pressure gradients are completely eliminated within the runner.

THE TURBINE TYPE FAN.

Late in 1941, at the St. Louis plant of the Curtiss-Wright Corporation, the development of an aircraft cooling fan with a pressure coefficient of 2·7 was undertaken, chord/pitch ratios greater than 2 were employed, and the blade design was based entirely upon consideration of the inter blade passage requirements. The blade camber lines and thickness distributions were calculated so as to make the inter passages as efficient as possible ; airfoil theory and geometry were completely disregarded. This procedure is employed in the design of turbine blades, and fans of this type have been referred to as turbine type fans.

During the development of the fan, the paper on the Schicht theory[4] was brought to the attention of the designers. Since a high pressure rise was contemplated within the runner, the paper was carefully studied and an investigation of turbine flow geometry was made. It was concluded the paper was over pessimistic in this regard. The design was influenced to the extent that the static pressure rise within the runner was reduced 30 per cent by partial " Schichting."

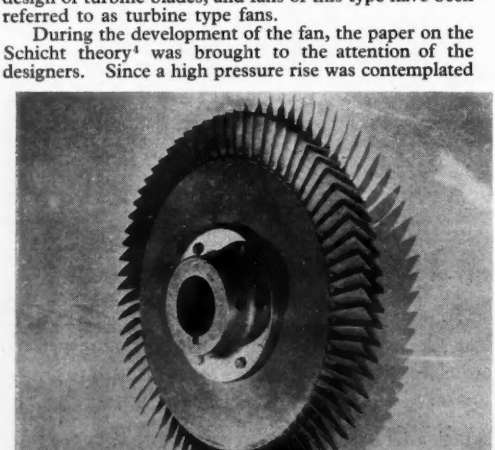

Fig. 3. **Sheet Metal Fan. Courtesy—Curtiss-Wright Corp.**

The fan was constructed in St. Louis and tested at the Massachusetts Institute of Technology in July, 1942. It was 21 ins. in diameter. The design pressure coefficient of 2·7 was obtained at the design flow. At higher flows the pressure coefficient went slightly above 3. This rising pressure curve substantiated the Wattendorf theory mentioned earlier. The efficiency was 80 per cent. These data were based upon total pressures measured several inches behind the aft vanes. Approximately 70 per cent of the head was static pressure at the design point. Loss within an after diffuser was found to be quite excessive. This fan is shown in Fig. 2. A full scale model of this fan was later installed and flown on a B-23.

Encouraged by these results, a number of the aircraft companies inaugurated research programmes on this type of fan. Investigating the possibility that equally good results might be obtained from curved sheet metal blades, a number of sheet metal fans were constructed. Fig. 3 shows such a fan built at the Research Laboratory of the Curtiss-Wright Corporation, in Buffalo. Surprisingly good results were obtained from these relatively crude designs, however the efficiencies were down about 5 per cent, and the range of efficient flow was considerably reduced. A number of such fans, constructed at the Wright Aeronautical Corporation, are shown in Kenneth Campbell's paper, " Engine Cooling Fan Theory and Practice."[5]

The success of the St. Louis fan also indicated the Schicht theory to be misleading. Two high pressure coefficient fans similar to the St. Louis fan, but with no " Schichting " were built at the Buffalo Research Laboratory. One was designed for a pressure coefficient of 1·25 and the other 1·80. These fans agreed well in tests with theory. The 1·25 pressure coefficient fan had an almost constant pressure curve with an efficiency of just over 80 per cent. The 1·80 pressure coefficient fan had a rising pressure curve with its peak slightly above 2·0. Its efficiency was 74 per cent. Both fans were tested with inlet vanes designed to prerotate the air an amount equal to half the runner peripheral speed. In each case, the pressure was increased by approximately 50 per cent. The higher pressure fan attained a pressure coefficient of slightly greater than three, where the efficienty fell to 68 per cent. At this point the flow coefficient was extremely high ; Q/ND^3 being almost 2·0.

The pressures were based upon total pressures aft of the fan, determined by measuring the static pressure after the fan and adding to it the calculated velocity head based upon the known flow and annular area of the fan. This method gives the actual static pressure rise developed across the fan blades. The lower pressure fan is shown in Fig. 4 and the higher in Fig. 5.

The St. Louis fan was brought to Buffalo and tested on the same test stand. By taking pressures in an annular diffuser behind the fan at a point where the velocity corresponded to the fan inlet velocity, results corresponding to those mentioned above were obtained. At corresponding pressure coefficients, the " Schichted " St. Louis fan was found to be considerably less efficient. At higher flow coefficients, the comparison became even more unfavourable for the Schichted fan. The Schichting, which is a contraction of the annulus through the fan, apparently acts as a constriction to the flow. Since the fans were very similar in all other respects, it would appear, the Schichting is not beneficial. This indicates the difficulties of diffusing within a curved runner passage are not as serious as those within an annular diffuser behind a fan, where un-

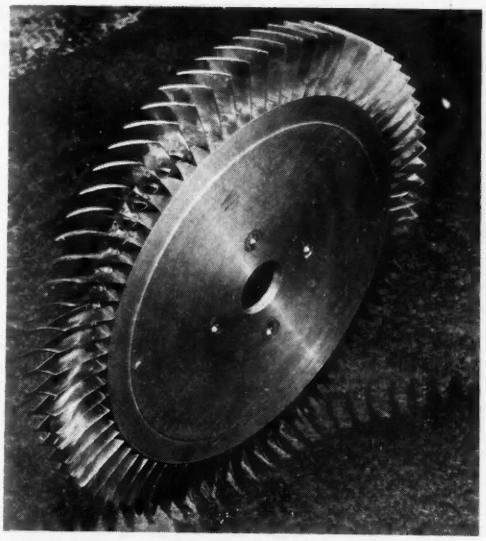

Fig. 4. **Turbine Type Fan—Axial Discharge. Courtesy—Curtiss-Wright Corp.**

favourable boundary layer conditions and turbulent flow exist.

THE TURBINE TYPE AXIAL-FLOW COMPRESSOR.

In applying the turbine type design to the axial-flow compressor, a number of questions become apparent. First, is the question of what *Mach* number to design to. The conventional airfoil type compressor seems to be limited to 70 per cent. The steam turbine, which resembles closely the turbine type fan, operates well at a *Mach* number of unity. Once the *Mach* number is decided, a design pressure coefficient must be chosen. The first thought is to design for as high a pressure coefficient as is consistent with good efficiency. These data are available from low speed tests. A check of the higher pressure coefficient designs indicates a disappointingly low pressure rise for a given *Mach* number.

This is due to the development of very high velocities at the aft vanes in these high pressure designs. In order to maintain these velocities below the maximum permissible *Mach* number, the wheel must turn relatively slower, thus the lower pressure. A plot of the obtainable pressure for a given *Mach* number versus pressure coefficient indicates a maximum at a pressure coefficient of approximately 1·25. Here the direction of discharge from the runner is directly aft, or axial, relative to the wheel. The fan in Fig. 4 is designed on this basis. This design point is significant from many standpoints. The relative velocity at the runner blade leading edge is equal to that at the aft vane leading edge. The theoretical or ideal pressure curve is constant at this point, becomes negative at lower pressure coefficients and positive at higher. A theoretical efficiency based upon a constant loss coefficient is at a maximum here, decreasing on either side. At this point, a maximum pressure for a given velocity is obtained, which would indicate low noise level. Tests have proven this design to be unusually quiet. Compressors of this type have been constructed, but no data are available as yet.

COMMERICAL BLOWERS OF THE TURBINE TYPE.

Late in 1944, the Buffalo Turbine Corporation undertook the development of a line of commercial

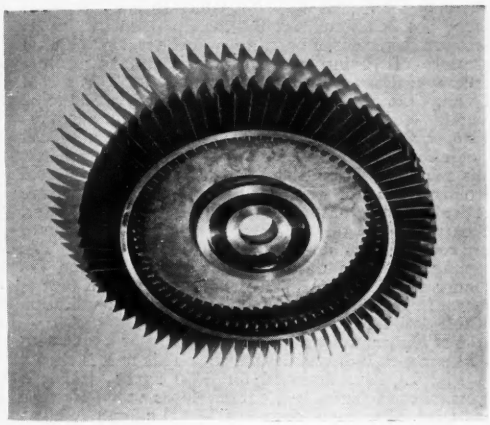

Fig. 5. **Turbine Type Fan—High Pressure. Courtesy—Curtiss-Wright Corp.**

blowers designed on the turbine principle. In aircraft cooling fan installation, relatively high velocities are maintained after the fan, and in compressors, several stages are in series. Thus, total pressures are important in these applications. However, in a commercial utility blower, the static pressure is usually the more important. Also often of great importance is the noise level. In the first design, an axial discharge, relative to the wheel, was chosen because of its favourable efficiency and noise characteristics. The number of blades was kept to a minimum for economy and to maintain a low noise frequency. The hub diameter was made as small as possible, 60 per cent, to minimize the diffusion after the fan and to permit a maximum of flow.

As stated earlier, these designs develop unusually high flow coefficients. It became apparent that the flow would be so great as not to permit the usual practice of discharging directly from the fan annulus into the duct. Without an effective diffuser at this point, excessive losses would be incurred.

This first unit was 14 ins. in diameter and turned 3450 r.p.m. with a direct connected motor. The hub

Fig. 6. **14 in. Diameter Commercial Turbine Blower.**

was only 8·4 ins. in diameter, which meant the motor could not be more than 8·4 ins. in diameter. At a pressure coefficient of unity, the wheel developed a total pressure of 10 ins. of water maximum, and had a maximum flow approaching 10,000 c.f.m. This meant a 20 h.p. motor, less than 8·4 ins. in diameter, had to be found. No such motor was available, but a manufacturer was found who agreed to develop a special motor for the blower. The motor, 8 ins. in diameter, was subsequently built and delivered. Air for internal cooling of the motor is tapped from an annular aperture at the beginning of the diffuser at the rear of the motor. This serves the double purpose of cooling the motor and removing the boundary layer for the diffuser. The cooling air is readmitted to the stream between the runner and aft vanes. This first experimental unit is shown in Fig. 6. It is the first commercial application of this design principle.

For higher pressures, an 18 in. diameter *a* unit with a 70 per cent hub was developed. This unit is shown in Fig. 7. Also designed for 3450 r.p.m., it has a pressure coefficient of 1·4. It developes a total pressure of 24 ins. of water at a flow of 15,000 c.f.m. Weight savings, resulting from the high flow coefficients and use of the special motors, have reduced the weights of these units to approximately 30 per cent of conventionally designed units.

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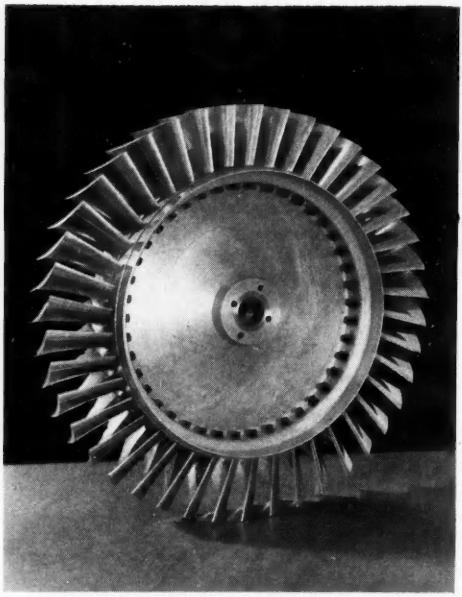


Fig. 7. **18 in. Diameter Turbine Blower Runner.**

[5] Campbell, Kenneth, "Engine Cooling Fan Theory and Practice," *S.A.E. Journal*, September, 1944.

SCIENCE FOR LIFE OR DEATH.

By Brigadier General DAVID SARNOFF, President, Radio Corporation of America. (From *New York Times*, August 10th, 1945.)

SCIENCE, under the direction of evil agressors on the one hand and in the hands of freedom's defenders on the other, has developed the twin forces of speed and explosive power to a point where a short step will make it possible to demolish whole cities in a single stroke. A third world war a generation hence would be so horrible in its power of destruction as to constitute a threat to civilization itself!

Only a few months ago, German rocket bombs fell on England at a speed so great that they exploded on the target before they were heard moving through the air. At the same time, the Allied Air Forces dropped, on German industrial centres, bombs so powerful that a single one wiped out an area larger than a city block.

But these demolitions were only hints of what is to come. Within the next ten or twenty years, rocket bombs may travel at speeds measured in thousands, instead of hundreds, of miles an hour. It is possible that these bombs will be loaded with new power that could obliterate a metropolis.

So terrifying in fact are the prospects of these new weapons that should some aggressively minded nation be the first to develop them, it might be tempted to use them immediately; to wait might mean its own eventual destruction. There may be no second chance!

We must therefore be on our guard. The first hope for civilization lies in a world organization to achieve and maintain a lasting peace. We must turn to science now for *new* weapons of offence and defence. We must have the means of detecting enemy-guided projectiles hundreds of miles from our coast. And we must have similar projectiles, or rays which we can instantly release to seek and to destroy these new forms of flying death before they reach their targets.

Modern war is not only army against army, navy against navy and air fleet against air fleet. Behind each of these are the scientists of one country against the scientists of the enemy, laboratory against laboratory, technical production against technical production. The brains and skills of scientists may determine the outcome of a future war.

Young Scientists are Needed.

Universal military training is an all-important factor for future security, but alone it is no guarantee. Scientific preparedness must parallel military preparedness. It is not enough to train youth for warfare. Those with an aptitude for science should be trained for research and engineering. It may be more important that such a boy be trained in the sciences than that he be drilled as a foot soldier, a sailor, or a flyer. The daring and initiative of young men is as important in the laboratory as on the battlefield.

In peacetime as well as in war, research must be maintained on a wide basis in order to seek solutions of scientific problems from as many angles as possible. There cannot be too many laboratories; each presents opportunity for scientists to test and to develop new ideas. Competition among them is the spice of invention.

National Security at Stake.

No time should be lost in the consideration of these factors of national security. Discussion of the subject is vital to the public interest. Enough news has been published to reveal the urgency of the situation without disclosing other developments which still are military

secrets. When the full story can be told, the vital necessity for scientific preparedness can be more thoroughly demonstrated. But in the meantime it must not be overlooked that a future war will be, from the outset, a scientific war. To-day, a vast geographical area, with a large population and unlimited mass production, no longer makes a nation secure, any more than does a mountain range or an ocean.

Freedom of Science is Vital.

It was through the perversion of science that Germany was able to wage two wars within a generation; and it was science that boomeranged to defeat her because she made slaves of her scientists and compelled them to work only for annihilation and conquest. This is a lesson free nations should never forget. Science must be kept free—there must always be freedom to experiment, to invent and to produce. "The empires of the future," said Winston Churchill, "are the empires of the mind."

Dr. Vannevar Bush, Director of the Office of Scientific Research and Development, recently told a Congressional Committee, in Washington, that the war with Germany was "a very serious and dangerous war where we have been in competition with a highly qualified enemy from a technical and scientific standpoint." He added, "I believe that history will show that the best way to fight a war, if it is going to be a highly scientific and technical war, is under a democratic form of government."

Wars are fought primarily with weapons which are developed before the fighting begins, Secretary of the Navy, James V. Forrestal, said in urging continued study and development of jet propulsion, rockets, gas turbines and other still secret devices. He emphasized that if a nation is to be scientifically prepared, its preparedness must be worked out in peacetime.

A Warning from Sweden.

From Sweden comes a warning by the inventor Sven Lindequist. He predicts that in the next war, guns will be antiquated and obsolete. He foresees rocket propelled shells weighing up to 10 tons, hurled with minute precision. He contends that the fighting fronts will not depend upon transport and supply lines, because the shells will be fired directly from underground factories some 400 miles in the rear into sectors just behind the front, where their explosive charges will be injected before they are fired on the enemy. Mr. Lindequist was one of the first, back in 1924, to predict sub-stratosphere bombing and high-altitude aviation engines. Now he forsees that jet and rocket-propelled shells will be handled with such accuracy that it will be possible to hit a target hundreds of miles away.

New Age in Aviation.

Jet propulsion has opened a new age in aviation, and created new implements of warfare. Planes of the future will fly above the earth's heavy atmosphere, at extremely high altitudes where air resistance is negligible. It is from such a height that rocket-propelled high-flying robot aircraft travelling at many times present-day speeds and dropping with meteoric speed, may bury themselves deep into the earth with an impact that will shatter everything over a wide area. Craters will be blasted in the earth to make it as barren and pocked as the face of the moon. Caves and subterranean tunnels are no impregnable fortress.

The buzz-bomb that winged its way across the English Channel in 1944 was but an insect compared to the robots of destruction that may spring from the scientific cocoon of the V-2 which rained on London. Jet-propelled monsters guided by radio and locating targets with a radio "eye" are destined to obliterate cities far beyond the horizon, should a third world war occur.

The sneak attack of an explosive projectile falling like a giant meteor from the stratosphere will be one of the deadliest "secret weapons" of the future. Great cities may be destroyed even before a nation knows it is being attacked.

I doubt whether the American mind could be induced to inflict such annihilation even upon a future enemy it may suspect, before that enemy attacks. But if America is not on the alert with new defensive as well as offensive weapons, it may find itself powerless and devastated if some other nation strikes first with these new forces of destruction.

Statesmen, as well as scientists, must realize what is ahead if nations, large or small, rearm by means of science and some day out of fear, hate, or even curiosity, decide to spring the switch. *Civilization cannot survive a third world war.*

Science Moves Quickly.

There is no security in the argument that many decades may pass before science exhausts the ultimate possibilities of dealing death from the skies. Science moves quickly as years are measured. When Marconi first signalled across the English Channel, he was told by experts that radio waves never would be able to cross the oceans. Nevertheless, two years later, Marconi spanned the Atlantic with electromagnetic waves. Before he died, he heard his signals through space encircle the globe. No greater delay may be in prospect for guiding missiles through space!

Power politics and diplomacy, as tools to shape the destinies of nations and the lives of people, are dwarfed by the potential power of science. The peacemaker who overlooks science, neglects future security. A nation may be stripped of its fleet, airforce, and army, but if its laboratories are intact and its scientists unfettered, they will hold in their hands a power that may challenge any military and naval force.

Questions a Scientist Asks.

Dr. Karl T. Compton, President of Massachusetts Institute of Technology and Chairman of the Research Board for National Security, has said that if we are not to become an easy and inviting prey to the next well prepared aggressor, we must be alert in our own preparedness for what may come. He asked, who can tell what this may be? Pilotless aircraft? Automatically guided bombs? Disease germs? Long-range bombardments with super-explosives? Or, perhaps death-dealing devices we cannot even envisage?

What can we do to keep such horrors from being unleashed, asked Dr. Compton, or to protect ourselves against them if they are? He answered that America must look forward, not backward, on the significance of science to future national security.

Civilization in Danger.

To-day civilization is in imminent danger. Cities can be wiped off the map—Lidice, Berlin, Cologne, Stalingrad, Tokyo and Kobe are stark testimony for the future. Scientific advances will make possible destruction on a global scale far more terrifying than in the war against Germany and Japan. There will be universal ruin. We have but to look upon Europe for the evidence, as one eye-witness described Berlin "lying dead and unburied under the sunlight—a sombre reminder of what another war will mean to cities."

So vast are the new frontiers of science opened by research, that within the next generation military, naval and air forces, as we know them to-day, will be completely revolutionized.

Rockets are no Dream.

Electronics is charting new pathways through the air and above the air, where pilotless planes will fly to reach a target anywhere on the globe.

These long-range projectiles are no idle dream. Experts have reported that the Germans had planned to bomb the United States with V-2 rockets having a range of at least 3000 miles. Our timely bombing of experimental bases helped to save New York from such attacks, for German scientists had these trans-Atlantic rockets in the blueprint stage. By a six months margin, V-E Day also thwarted the German plans to demolish London. The Nazis are reported to have figured that given two years more, they could have built a rocket bomb that would travel 15,000 miles. The Germans had what American investigators described as " an amazing rocket assembly plant " 800 feet underground in the Kohnstein Mountains, and there with 12,000 slave labourers, they produced hundreds of buzz-bombs.

We are told that German blueprints for V-weapons were sent to the Japanese before the Nazi collapse. German scientists were experimenting feverishly on new secret weapons when the war in Europe ended. The Germans also had completed test models of new rocket weapons, several types of which were radio-controlled. They were being made ready for production when V-E Day nipped them in the bud.

Outlook for New Weapons.

The end of the European war brought to light the evidence that development of new weapons of warfare is passing through several interesting stages :

1. Production of long-range high-speed missiles.
2. Guidance of these missiles either by self-contained or outside means, such as radio.
3. Intensive research into the possibilities of release and control of atomic energy.

It is to be noted that the passage from each of these stages to the next has been greatly speeded by developments during World War II, as for instance, in the rapid development of jet and rocket bombs, the flying speed of which lies between 300 and 3000 miles per hour. In flight, they already have attained an altitude of 60 miles, and this height will be substantially increased. The explosive load or warhead of these 40 to 50-foot bombs contains about 2 tons of high explosive, the entire bomb weighing from 10 tons to several tens of tons.

Within ten years or so, we may face a new form of long-range guided missile whose flying range will enable it to span the oceans. It is not too much to expect that speeds of 5000 to 10,000 miles an hour will be attained, and that these speeds will be suitably reduced for landing purposes and to prevent overheating the bomb by air friction, with consequent premature detonation.

The flight path of such a weapon will be hundreds of miles above the surface of the earth, where the absence of atmosphere enables almost unlimited speed. The warhead of such bombs alone will carry at least five tons of explosives and thus will be equivalent to the larger present-day bombs. Alternatively, it may carry thousands of incendiary bombs. The weight of this guided bomb might be 100 tons or more and its length exceed 100 feet. Such bombs may be so accurately guided by radio or otherwise that they would land within a few hundred yards of the selected target in the heart of a city on the other side of the ocean and cause destruction beyond anything produced thus far.

Unlocking Atomic Energy.

To supply the terrific driving force required by such a weapon, we find man struggling with Nature to learn the secret of atomic energy. Scientists know that locked within the atom is a reservoir of tremendous energy. Atomic power resides in the very centre of the nucleus of the atom. It is a high-calibre energy tightly locked into place and requires extraordinary means for its release.

The Sun Offers a Clue.

Astronomers, aided by elaborate scientific investigations, have been led to believe that matter at the centre of the sun, at a temperature well above 20,000,000 degs., is in part turned into energy which flows to the surface of the sun and then is radiated into space. A minute fraction of the atomic energy so radiated by the sun strikes and warms the earth ; without it this world would be a cinder spinning lifeless in space. If that theory is true, the star-studded sky with its myriads of suns all pouring atomically-generated energy into space would seem to be the first revelation of the existence of such energy and of the fact that it is capable of release.

Some idea of the magnitude of atomic energy is found in the estimate that a glass of water, transmuted from matter into energy by the release of the power stored in the nuclei of its atoms would drive an ocean liner across the Atlantic and back. And scientists tell us that a few pounds of a suitable metal, atomically detonated in a metropolis, would convert that city into a column of incandescent gas flaming high into the sky. This is not destruction—it is annihilation !

There also is a second reason for believing in its existence. The heavy metal, uranium, has been found in several forms or modifications known as " isotopes." One of them—and the most remarkable—has been identified by scientists as " Uranium 235." It is this metal that has for the first time, under special electrical bombardment in a vacuum tube, released some of the energy of its atoms. Under such treatment, Uranium 235 atoms have released considerably more energy than was applied to them. The excess energy has come from the nuclei of the atoms.

This experiment has, therefore, shown that man, using terrestrially available methods, can release certain amounts of atomic power and points the way to greater results for the future. Freedom to experiment will solve the remaining problems in time.

Military Applications of Atomic Power.

In the field of military applications, atomic energy promises results that challenge the imagination. The range of a flying missile propelled by such energy could encircle the world. A nation could, without notice, launch a deadly cloud of these missiles accurately directed at an opposing nation. Such atomically-propelled bombs could travel thousands of miles an hour at heights hundreds of miles above the earth. The warheads of such projectiles would need to contain only a few pounds of the material to be decomposed into energy by a mechanism capable of detonating the nuclei of the atoms.

When a bomb of this sort landed in a city within a moderate distance of a selected target, it might well convert a large region surrounding it into gas and debris. In view of its range of destruction, accuracy of aim no longer is a major factor. A scattered pattern of such bombs not only would destroy all life, but would convert the city into a bed of rock, ashes and dust.

It must not be overlooked, however, that never has science been outwitted in finding a weapon of defence for every new weapon of offence. The flying bomb is not likely to be an exception ; it will not go unchallenged. It is not difficult to envisage accurately guided " bloodhound " missiles which will take off against the approaching bombs and, under scientific control, locate and destroy them before they have a chance to strike. But here we face new forces of destruction, prevention of which must be measured in minutes or in seconds instead of months or years, as in the past. This only emphasizes the great need for constant research to develop defensive as well as offensive weapons for instant use.

What will man do with these astounding facilities that science is creating ? Will he use them for beneficent purposes ? Will he use them to make the world a better and happier place, and to provide abundance everywhere so that those who now lack the basic requirements

for comfortable living may secure them? Or will man prepare to use these agencies for aggression and destruction? No one knows. Yet no more important question faces the world.

Voice of Science Vital.

As I see it, our great hope for world peace can best be advanced by achieving freedom from want, through man's ingenuity in atomic energy, electronics, chemistry, physics and the other sciences. All around us Nature inspires and offers the perfect model for science to emulate and duplicate, whether it be an artificial potato or a kernel of wheat, oil or cotton. Already by ingeniously producing artificial fibres man no longer is dependent upon the silkworm or the rubber tree; also he has plastics for wood, and vitamins condensed into tablets. He has produced and harnessed electricity, which as lightning defied him to put electrons to work. He has created artificial gas and now the sun daily dares him to bottle its tremendous heat for use at will. With that revolutionary accomplishment it would not be necessary to dig for Nature's black diamond—coal. I am sure that raw materials of endless varieties from ores to paper, from clothing to food, will emerge from the test tube, and from out of the air itself.

Peace now depends upon recognition by all nations of their individual responsibilities to prevent war.

"To-day, science has brought all the different quarters of the globe so close together that it is impossible to isolate them one from another," said Franklin D. Roosevelt in an address he wrote the night before he died, and which he had planned soon to deliver. "To-day we are faced with the pre-eminent fact that, if civilization is to profit, we must cultivate the science of human relationships—the ability of all peoples, of all kinds to live together, to work together in the same world, at peace."

MOMENT DISTRIBUTION OVER STRUCTURES CONSISTING OF COLUMN SUPPORTED TANKS AND PRESSURE VESSELS.

By RAY H. SPRING, Structural Engineer, The Stacey Manufacturing Co.

THE problem of determining this moment distribution presents itself in the design of any vertical tank which is supported on legs or columns connected eccentrically to the tank shell, as is a common practice. A thorough search of technical literature having failed to disclose any stress analysis of such structures, which takes into consideration the stiffening effect of the cylindrical tank shell and the bottom of hemispherical, ellipsoidal or conical form in resisting part of the external moment imposed upon it, has prompted the writer to make this investigation.

In figure (1a) let w equal the load on each column in pounds and let e equal the eccentricity of the connection in inches. Then $w \times e$ equals the external moment M. Let c equal the length of plate arc between columns in inches and R_1 equal the neutral line radius of the cylindrical shell and R_2 the mean radius of the bottom normal to a meridian.

The column bending moment diagram is approximately as shown in figure (1b) and the deflection curve takes the form shown in figure (1c). Since the elastic curve is tangent to the vertical at the base of the column, its angle of deflection Θ from the vertical at the top of the column equals the area of the $\frac{M}{EI}$ diagram. Now, let M_{AB} and M_{BA} denote the moments at points A and B respectively of the column AB and let h equal the height of the column in inches and I its moment of inertia, and E, the modulus of elasticity. Since one half of the moment applied to the column at B is carried over to the fixed end A,

$$M_{AB} = \tfrac{1}{2} M_{BA} \text{ and } \Theta = \frac{M_{BA}\,h}{3EI} + \frac{M_{AB}\,h}{6EI} \text{ or}$$

$$\Theta = \frac{5\,M_{BA}h}{12\,EI} \quad .. \quad .. \quad (1)$$

Let the resisting moment of a one inch vertical strip of the cylindrical shell be M_1 and the resisting moment of a one inch meridional strip of the bottom M_2. Then

$$M = cM_1 + cM_2 + M_{BA} \quad .. \quad (2)$$

It has been proved * for the general case of any shell which has the form of a surface of revolution, that the angular deflection of the meridian produced by a moment M_0 in the plane of the meridian is $\Theta = \frac{M_0}{\lambda D}$(3), where λ is the wall characteristic and equals $\sqrt[4]{\frac{3(1-\mu^2)}{R^2 t^2}}$ in which μ equals Poissons ratio (·3 for steel), R equals the mean radius of the shell in a plane normal to a meridian, and t equals the shell thickness in inches. D is the flexural rigidity of the shell plate and equals $\frac{E\,t^3}{12(1-\mu^2)}$ in which E equals the modulus of elasticity (30,000,000 for steel). For steel the value of λ becomes $\frac{1{\cdot}285}{\sqrt{Rt}}$ and D becomes $\frac{30{,}000{,}000}{10{\cdot}92}\,t^3$, making $\lambda D = 3{,}530{,}000\,\frac{t^3}{\sqrt{Rt}}$.

Let $\frac{5\,h}{12\,EI}$ in equation (1) be represented by d (equals ·000,000,013,89h/I for steel) and let $\lambda_1 D_1 = a$ and $\lambda_2 D_2 = b$ in which the subscripts 1 and 2 denote the

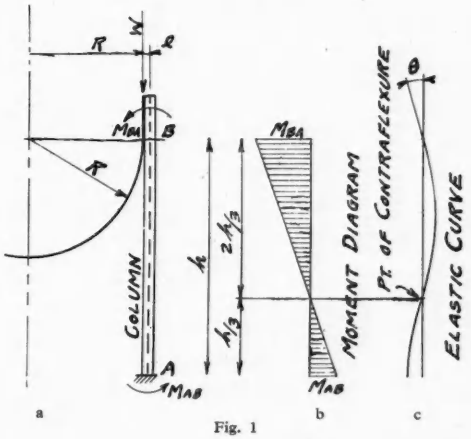


Fig. 1

* This formula was first developed in "Uber die Festigkeit Achsensymmetrischer Schalen" by J. Geckeler, Forschung auf dem Gebiete des Ingenieurwesens, Heft. 276. 1926.

cylindrical shell and the tank bottom constants respectively. Since the deflection angle Θ from the vertical at the point B must be the same from continuity for the column, the cylindrical shell and the bottom plate, we may write $\frac{M_1}{a} = \frac{M_2}{b} = d\,M_{BA}$ or $M_1 = ad\,M_{BA}$ .. (4) and $M_2 = bd\,M_{BA}$ .. (5). Substituting the values of M_1 and M_2 from equations (4) and (5) in equation (2) and solving for the column bending moment we get $M_{BA} = \frac{M}{cd\,(a+b)+1}$ (6).

This value can in turn be substituted in (4) and (5) to get the numerical values of the bending moments in the shell components.

To illustrate with a practical example, take a pressure tank 40′ 0″ in diameter supported on 12 columns consisting of 12″ wide flange beams at 40 lb. per ft. with an unstiffened length of the strong axis h equals 270″ and eccentricity e of its connection to the tank about this axis equal to 5·58″. Referring to this axis the moment of inertia I equals 310·1, radius of gyration r equals 5·13″, and section modulus s equals 51·9. Let the cylindrical shell thickness t_1 equal 1-3/32″, and let the bottom be hemispherical with a thickness of t_2 equal 9/16″. The combined live and dead load on each column is W equals 79100 lb. The arc between columns on the cylindrical shell is c equals 126·7″. Then :—

$$d = \frac{5\,h}{12\,EI} = \frac{5 \times 270}{12 \times 30{,}000{,}000 \times 310{\cdot}1} = {\cdot}000{,}000{,}012{,}093$$

$$a = \lambda_1 D_1 = 3{,}530{,}000\ \frac{t_1^3}{\sqrt{R_1 t_1}} = 285{,}000$$

$$b = \lambda_2 D_2 = 3{,}530{,}000\ \frac{t^3}{\sqrt{R_2 t_2}} = 54{,}100$$

$$M = W \times e = 79100 \times 5{\cdot}58 = 441{,}600 \text{ lb. in.}$$

$$M_{BA} = \frac{M}{cd(a+b)+1} = \frac{441{,}600}{126{\cdot}7 \times {\cdot}000{,}000{,}012{,}093(285{,}000+54{,}100)+1} =$$

$$= 290{,}500 \text{ lb. in.}$$

The ratio of the bending moment resisted by the column to the total external moment is, in this case, $\frac{290{,}500}{441{,}600} =$ 65·75 per cent of the total external moment which is distributed to the columns and from which the column stress can be accurately calculated. The area of the column cross section A equals 11·77 square inches and the bending factor B_x equals ·227. Then the equivalent concentric column load equals 79,100 lb. direct load plus $B_x \,.\, M_{BA}$ which equals $·227 \times 290{,}500 = 66{,}000$ lb. The extreme fibre compressive stress equals $\frac{79{,}100+66{,}000}{11{\cdot}77} = \frac{145{,}100}{11{\cdot}77}$ equals 12,330 lb. per sq. in.

Since $\frac{h}{r} = \frac{270}{5{\cdot}13} = 52{\cdot}62$ giving an allowable column stress of 15,000 lb. per sq. in. by A. I. S. C. formula, the 12″ wide flange I-beam selected is of sufficient strength when suitably strutted and braced in the weak axis.

The moment distribution to the shell may now be computed by substituting in equations (4) and (5) $cM_1 = cdM_{BA} \,.\, a = 126{\cdot}7 \times {\cdot}000{,}000{,}012{,}093 \times 291{,}000 \times 285{,}000 = 127{,}000$ and moment per inch M_1 equals 1002·93 lb. in. for the cylindrical shell $cM_2 = cd\,M_{BA} \,.\, b = 126{\cdot}7 \times {\cdot}000{,}000{,}012{,}093 \times 291{,}000 \times 54{,}100 = 24{,}100$ and moment per inch M_2 equals 190·38 lb. in. for the hemispherical bottom.

The maximum hoop stresses produced by these moments are $S_1 = \frac{2M_1\lambda_1{}^2R_1}{t_1}$ and $S_2 = \frac{2M_2\lambda_2{}^2R_2}{t^2}$.

Substituting the numerical values for this case, we get

$$S_1 = \frac{2 \times 1002{\cdot}93 \times {\cdot}0792^2 \times 240{\cdot}55}{1{\cdot}09375} = 2770 \text{ lb. per sq. in.}$$

and

$$S_2 = \frac{2 \times 190{\cdot}38 \times {\cdot}1106^2 \times 239{\cdot}7}{{\cdot}5625} = 1985 \text{ lb. per sq. in.}$$

The stress due to pressure in the cylindrical shell at 50 lb. per square inch equals $\frac{50 \times 240{\cdot}55}{1{\cdot}094} = 11{,}220$ lb. per sq. in. and the stress in the spherical bottom equals $\frac{50 \times 239{\cdot}7}{2 \times {\cdot}5625} = 10{,}650$ lb. per sq. in. Then the total cylindrical shell stress equals 2,770 + 11,220 = 13,990 lb. per sq. in. and at the welded joints with efficiency of 85 per cent equals $\frac{13{,}990}{{\cdot}85} = 16{,}460$ lb. per sq. in. Similarly the total hemispherical bottom shell stress equals 1,985 + 10,650 = 12,635 lb. per sq. in., and at welded joints equals $\frac{12{,}635}{{\cdot}85} = 14{,}875$ lb. per sq. inch. Both of these total stresses are allowable for ordinary design. However, they can be easily modified by changing the shell thickness to suit any requirement or code. Let

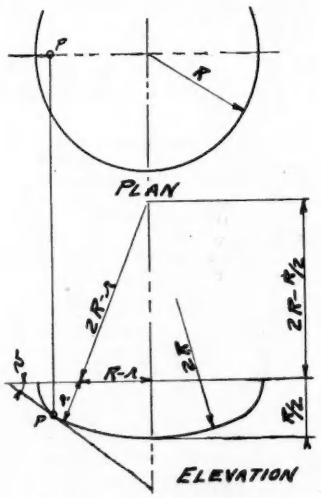
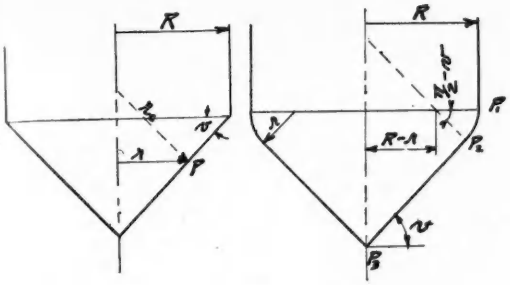


Fig. 2. Standard Ellipsoidal Head.

$$(R-r)^2 = (2R-r)^2 - \left(2R - \frac{R}{2}\right)^2$$

$$R^2 - 2Rr + r^2 = 4R^2 - 4Rr + r^2 - \frac{9R^2}{4}$$

$$2Rr = {\cdot}75R^2 \qquad r = {\cdot}375\,R$$



a b

Fig. 3

us note, though, that any such change will effect the moment distribution, a heavier plate taking more and a lighter plate less of the total external moment, necessitating a recalculation of the moment distribution for absolute accuracy. For an approximate ellipsoidal bottom with two radii $2R$ and r respectively (Fig. 2) the short radius r equals $\cdot 375R$ and the long radius equals $2R$.

$\text{Sin}^{-1}\left(\frac{R-r}{2R-r}\right) = \sin^{-1}(\cdot 38462)$ equals an arc of $\cdot 3948$ radians over which the radius of curvature is $2R$ and $\frac{\pi}{2} - \sin^{-1}\frac{R-r}{2R-r}$ equals an arc of 1·186 radians over which the radius of curvature is $1{\cdot}5R$. By substituting numerical values for R and r the mean radius of curvature for any particular case is easily computed and also the value of λ_2 as in the preceding problem.

In the case of a conical bottom (Figure 3a) it is readily proved geometrically that the radius of curvature r_c normal to an element at any point P is $\frac{r}{\sin v}$.

Hence the mean radius of curvature equals $\frac{R}{2 \sin v}$.

Where the conical bottom is combined with ellipsoidal as in figure (3b) the radius of curvature at P_1 equals R and at P_2 is $\frac{R - r + r\cos\left(\frac{\pi}{2} - v\right)}{\sin v} = \frac{R-r}{\sin v} + r$.

The average value over arc $\left(\frac{\pi r}{2} - vr\right)$ is $\frac{R + r + \frac{R-r}{\sin v}}{2}$

and the average value between P_2 and P_3 is $\frac{R-r}{2 \sin v} + \frac{r}{2}$.

For any special case the substitution of known values in the general formula will give a numerical value for the mean radius of curvature of the particular form of shell bottom considered, and the problem of moment distribution may then be solved as outlined above. In fact this method is applicable to any type of shell and bottom which is a surface of revolution and will yield an accurate determination of the supporting column and shell stresses.

NEW DEVELOPMENTS IN THE NITRIDING OF STEEL.

By CARL F. FLOE, Associate Professor of Physical Metallurgy; Massachusetts Institute of Technology, Cambridge, Massachusetts; and Associate Technical Director, The Nitralloy Corporation, 230 Park Avenue, New York, N.Y.

INTRODUCTION.

THE use of the nitriding process has increased during the war to the extent that it is now one of the most important methods for the production of hard, wear resistant, and abrasion resistant surfaces on steel. Over 100,000 tons of the Nitralloy grade of steel alone were manufactured in this country in 1944. In addition, some of the S.A.E. steels, stainless steels, high speed steels and chromium tool and die steels were treated in considerable tonnages.

The reasons for the increasingly wide application of the nitriding process are principally that: (1) a remarkably high surface hardness is obtained without subsequent heat treatment, (2) this hardness is maintained after heating to as high as 1200 deg. F., and the hardness is the same at 750 deg. F. as at room temperature, (3) the two properties above result in high wear resistance, (4) the tendency for seizing and galling is less than for conventionally hardened materials, (5) a minimum of warping and distortion occurs, and (6) the fatigue resistance of the steel, particularly the notch sensitivity, is greatly improved.

THE NITRIDING PROCESS.

The nitriding process consists of heating special alloy steels in contact with an active nitrogen containing medium at temperatures of from 925 deg. F. to 1050 deg. F. for periods ranging from a few minutes to 100 hours depending upon the depth of case desired and the steel being treated. For successful results the steel must contain elements in solid solution that are capable of forming nitrides, such as aluminium, chromium, molybdenum, vanadium, tungsten or titanium. The source of the nitrogen is most commonly ammonia, although salt baths containing cyanides are also used. Nitrogen from the decomposition of the ammonia or cyanides, diffuses into the steel where it comes into contact with the nitride forming elements. The result is the formation and precipitation of alloy nitrides along the crystal planes of the iron. It is this precipitation, which takes place at the nitriding temperature, that results in the production of an extremely hard case.

The nitride case, therefore, consists of the region beneath the steel surface where nitrogen has penetrated and precipitated the nitride forming elements. In addition, on the outer surface of the case, there is a region where the iron also has been converted to nitrides. This region, usually 0·001 to 0·002 inches deep, is known as the "white layer." Since it is very hard and brittle it is ordinarily removed by grinding or lapping after nitriding.

The common practice in nitriding has been to circulate the ammonia through the nitriding container at such a rate that the composition of the exhaust gases will be 70 per cent undissociated ammonia and 30 per cent nitrogen plus hydrogen, the latter resulting from ammonia dissociation at the steel surfaces. This is spoken of as "maintaining the dissociation at 30 per cent." Such practice insures an adequate supply of undissociated ammonia in contact with all steel surfaces, unless there are "dead" zones in the container due to poor circulation. Recent work has shown that the depth

of white layer on nitride cases is a function of the degree of ammonia dissociation and that this depth can be greatly reduced by nitriding at higher dissociations with no sacrifice in depth of useful case beneath the white layer. The recommended practice is to nitride for 5 hours at 30 per cent dissociation and the balance of the cycle at 85 per cent dissociation. If this is done adequate circulation of the ammonia within the container must be provided since nitriding will stop if the dissociation in a local zone rises above 90 per cent. Parts hardened by this method have a very shallow white layer and do not need to be ground or lapped before being put into service. In addition a considerable saving in ammonia costs results.

Salt baths for nitriding are becoming increasingly popular, particularly in the treatment of small parts and where large quantities are not involved. For high speed steel a bath made up of 50 per cent potassium cyanide and 50 per cent sodium cyanide operating at 1050 deg. F. is commonly used. Salt baths through which ammonia is bubbled are also employed and claims are made that such baths produce deeper cases for a given nitriding cycle. The depth of white layer is also less where salt baths are used compared to the use of ammonia at 30 per cent dissociation.

For protection of certain areas of parts against nitriding electroplated tin is still the most popular. Since tin melts below the nitriding temperature, it is held by surface tension only. To prevent " running " the depth of plate must be controlled between 0·0003 and 0·0005 inches. Tin may also be applied as a protection against nitriding in the form of a paint consisting of tin or tin oxide powder in a suitable carrier.

Bronze plate containing from two to ten per cent of tin is also used as a protection against nitriding. While the plating procedure is more difficult, the results are excellent and there is no danger of the plate " running " during nitriding. Copper, plated by special methods has also been proposed recently.* However, the effectiveness of this plate is still controversial, some nitriders claiming that it is difficult to obtain complete protection under all conditions.

NITRIDING FURNACES.

In recent years it has been increasingly recognized that good nitriding results can be more consistently obtained in furnaces that are specially designed for the purpose. The conversion of other types of heat treating furnaces is not recommended. Nearly all of the major furnace manufacturers in the United States build special furnaces for nitriding into which the two important provisions for successful nitriding are incorporated. These are : (1) adequate circulation of the ammonia over all surfaces to be nitrided, preferably by means of a fan, and (2) uniformity of temperature within the nitriding container. The importance of these two factors in obtaining satisfactory nitriding results cannot be overstressed.

One of the most important problems continues to be the selection of proper materials for the nitriding container and fixtures. Such materials should have surfaces that will not dissociate ammonia. Inconel is most commonly used, but in some cases becomes " poisoned " after a few years and starts to break down ammonia rapidly. The surface can be restored to a relatively inert condition by soaking for several hours at 1650 deg. F., followed by sand blasting. A more inert material is produced by porcelain enamelling of either 35–15 stainless or Inconel. Enamelled plain carbon steel may be used, but if the surface is chipped the exposed iron deteriotates rapidly and causes excessive dissociation. Oxygen free or phosphor deoxidized copper has been used successfully but lacks strength.

* Sternberger and Fahy : Metal Progress, 47, No. 2, 278 (1945).

Excellent salt baths in which uniform nitriding results can be readily obtained are also manufactured.

NITRIDING STEELS.

An increasing number of different types of steels are being nitrided. Any steel which contains the nitride forming elements previously mentioned may be hardened by this process. However, the degree of hardness obtained is a function of the amount and nature of the nitride forming elements present and the depth of case produced in a given cycle is inversely proportional to the alloy content. The aluminium containing steels, sold under the trade name of Nitralloy, produce the hardest cases consistent with good case depth. The S.A.E. steels of the chromium molybdenum or chromium vanadium types as well as some others are also nitrided, but the maximum hardness obtained is only about 700 Vickers-Brinell compared to about 1100 for the aluminium containing steels. All of the National Emergency steels are too low in alloy content to be hardened to any great degree.

The 5 per cent chromium and high carbon, high chromium types of tool steels are nitrided successfully by conventional methods after the ordinary hardening treatment. For many application the wear resistance is greatly improved and the tendency for metal pick-up, especially for drawing dies and punches, is reduced.

Considerable interest has been shown in recent years in the nitriding of high speed steel. This is ordinarily accomplished by the use of salt baths, the time of immersion ranging from 30 minutes to several hours at 1050 deg. F. Because of the high alloy content, shallow cases are produced, the range being from 0·001 to 0·004 inches. With the use of ordinary ammonia nitriding, the cases obtained are more brittle, probably due to a heavier white layer formation.

Some phenomenal improvements in high speed tool life after nitriding have been reported. These improvements are due both to the increased wear resistance resulting from the high surface hardness, and to the lower frictional characteristics of the nitrided surface. The latter results in less generation of heat and less tendency for metal pick-up or built up edges on cutting tools.

Engineering requirements for a material that has a combination of wear resistance and corrosion resistance have led to considerable interest in the nitriding of stainless steel. Since these steels always contain chromium and in some cases molybdenum and tungsten, they can be surface hardened by nitriding. However, before nitriding will begin it is necessary to destroy the thin, adherent film of oxide which covers the surface of such steels. So far no entirely satisfactory method that will guarantee uniformity in nitriding results has been reported. Nitriding in a salt bath through which ammonia is bubbled is claimed to be successful. In this case the salt destroys the oxide film after which nitriding proceeds. One company advocates destruction of the oxide layer by heating the parts in completely dissociated ammonia at 850–1050 deg. F. for several hours followed by introduction of the normal nitriding gas. Chemical methods of destroying the oxide film, such as pickling in hydrochloric acid have also been proposed. Due to the high alloy content, shallow case depths are always obtained.

The corrosion resistance of stainless steel is primarily due to the presence of chromium in solid solution in the iron. During nitriding this chromium is precipitated from solid solution as a nitride and therefore the surface cannot be expected to offer the same resistance to chemical attack. Therefore, while the corrosion resistance of nitrided stainless is better than that of other nitrided steels, salt spray tests show that it is less than that of non-nitrided stainless. Users of the process should take this into consideration.

Recently a new steel, still in the experimental stage,

has been developed for nitriding, which contains free graphite. A typical composition is

Carbon	.. ..	1·25–1·50 per cent
Silicon	.. ..	1·25–1·50 „
Manganese	.. ..	0·40–0·60 „
Aluminium	.. ..	1·00–1·50 „
Chromium	.. ..	0·20–0·40 „
Molybdenum	.. ..	0·20–0·30 „

Originally all of the carbon is in the combined form, but by a simple heat treatment prior to nitriding, approximately two-thirds of it is converted to free graphite uniformly distributed throughout the sorbitic matrix of carbide and ferrite. When such a steel is nitrided a typical case is produced except that it is porous due to the presence of free graphite. It is believed that a material of this type will find particular application where lubricated wear resistance is of prime importance. The soft graphitic phase provides oil reservoirs for maintenance of the lubricating film and the hard nitride surface provides maximum wear resistance.

Increasing recognition has been given to the fact that nitrided surfaces greatly improve the fatigue characteristics of steel, particularly the notch sensitivity. This has led to greater applications of the process particularly for internal combustion engine parts such as crankshafts. The improved fatigue properties are due to the high compressive stresses which are built up in the case during nitriding. These compressive stresses naturally resist localized surface tensile stresses which commonly originate fatigue cracks.

APPLICATION OF CONTROLLED ATMOSPHERES TO THE PROCESSING OF METALS.

By C. E. Peck, Manager, Industrial Heating Section, Westinghouse Electric Corporation, East Pittsburgh, Pa.

In this paper, read before the American Society of Mechanical Engineers, the term "controlled atmospheres" is defined as that produced separately from specific equipment especially designed to make a gas or mixture of gases of a given composition. The development and application of separately controlled atmospheres has grown rapidly for several years, and the uses of these atmospheres are now an important component in a great majority of heat treating processes where quality control and uniformity of the product are required. It is now possible to accurately control or entirely prevent the oxidation of practically all ferrous and non-ferrous metals and their alloy combinations, when these metals are heated to elevated temperatures. On carbon steels and alloy steels it is also possible to accurately control or prevent the loss of carbon (decarburization) or gain of carbon (carburization) as well as to accurately control the amount of carbon added to the surface of steel (gas carburizing). Because of these developments, large tonnages of metals can be heated without oxidation and expensive pickling and cleaning costs are eliminated.

Mass production of finished machine parts which require heat treatment can be processed without loss of surface hardness during heating (decarburization) and without further grinding or cleaning. Metals can be furnace brazed without oxidation. Controlled atmospheres are finding many applications in the sintering and powder metallurgy fields. In the fields of welding, forging and melting of metals the use of separately controlled atmospheres is at present quite limited, but future developments may lead to wider uses of atmospheres in these fields of metal processing.

Discussion of General Combustion Range.

Before discussing the principal types of atmospheres a brief general description will be given on the complete combustion and cracking range of a fuel gas as related to varying amounts of air mixed with the fuel.

The range is illustrated by the set of curves, Fig. 1 Using methane, for example, as the base fuel and mixing it with proper air ratios as indicated on the curve, the variation in approximate gas composition covers the range from complete combustion to complete cracking. At a particular air to gas ratio the approximate amounts of hydrogen, carbon monoxide, carbon dioxide, water vapour and nitrogen are given. A curve of this type is useful in giving a general picture of what gas composition can be expected over the range from complete combustion to complete cracking. A curve of this type can be calculated for every type of fuel gas commercially available for use in generation of prepared furnace atmospheres.

Between the right-hand side of the curve showing complete combustion and the left-hand side showing complete cracking, the actual atmosphere compositions obtained will depart somewhat from "idealized" composition indicated on the curve for the following reasons:

(1) In the partial combustion range the actual amounts of hydrogen compared to water vapour formed will depend on the design of the gas generator. The same is true for the amount of carbon dioxide compared to amount of carbon monoxide. The variations are due to size of combustion space, time allowed for reactions, type of catalyst used, temperature level of reaction, etc. All of these factors depend on the individual equipment design.

(2) In practical gas analysis the amount of water vapour generated in the reactions is always partially removed by condensing out the steam of combustion down to temperatures and dewpoints corresponding to normal atmospheric conditions. Per cent water vapour given on curve is that generated during reaction before any condensation or removal.

(3) At the lower air to gas ratios on the partial combustion range and also on complete cracking range there are small amounts of residual methane. This will show up on actual gas analyses but is not shown on the general curves using methane as an example.

(4) The heat generated or absorbed is shown on the curve. This represents approximately the heat of generation or heat of absorption required chemically to produce the compositions shown. The heat losses from the generating equipment and the sensible heat corresponding to the temperatures of gases leaving the generating equipment must be subtracted from heat values shown to give net heat generated or absorbed,

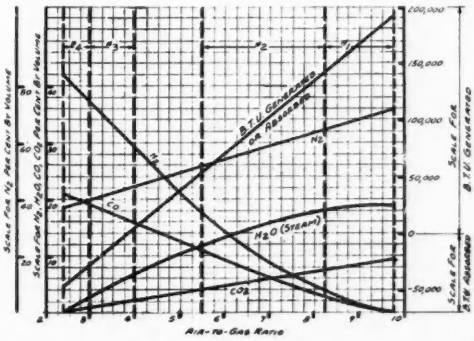


Fig. 1. **Curves showing combustion properties of methane over range from complete combustion to complete cracking.**

and has the effect of decreasing the net heat generated and increasing the net heat absorbed. For this reason the actual air to gas ratio on the curve at which heat is neither generated or absorbed is higher than that indicated on the curve. For a given gas generator temperature, the increment by which the air gas ratio is higher depends on heat losses and design of the particular gas equipment.

The following summarizes the important commercial atmospheres produced from either fuel gases or anhydrous ammonia. Each atmosphere is briefly described from standpoint of composition, cost and equipment required to produce it.

Atmosphere No. 1—Completely Burned Fuel Gas.

If any commercially available fuel gas is mixed with the proper amount of air it may be burned under controlled conditions to form CO_2, H_2O and N_2. If this combustion process is carried out with a slight deficiency of air there is no oxygen present in the resultant atmosphere and small amounts of hydrogen and CO will be present in addition to the gases given above. This resultant atmosphere corresponds to a ratio (assuming methane as the fuel) slightly to the left of the line representing complete combustion shown on curves of Fig. 1.

$$CH_4+2O_2+7{\cdot}52\ N_2$$
$$CO_2+2H_2O+7{\cdot}52\ N_2$$

Similar reactions take place with gaseous fuels containing CO, H_2 and illuminants or heavier hydrocarbon gases such as propane (C_3H_8) and butane (C_4H_{10}).

A representative composition of prepared gas when burning methane with a slight deficiency of air would be CO_2=10 per cent, CO=0·5 per cent, H_2=0·5 per cent, CH_4=0·0 per cent, O_2=0·0 per cent, N_2=89 per cent. Dewpoint corresponding to approximately room temperature conditions unless auxiliary drying equipment is used. This atmosphere is inert and non-explosive and can be set with somewhat higher reducing properties as indicated by range given on curve of Fig. 1. This is desirable in many cases in order to overcome effects of impurities in the furnace and on the work being processed.

This particular atmosphere is among the cheapest produced since the minimum of fuel is used due to the lean mixtures involved and can be produced for approximately $·08 per 1000 cu. ft.

Equipment A.—A typical generator for producing this gas is shown in Fig. 2. A schematic general arrangement and flow diagram is shown in Fig. 3. The gas mixing pump draws air through a filter; the air flow automatically regulates flow of gas to give a predetermined air to gas ratio for variable flow demand. The air and gas, after flowing through visual flowmeters, mix together at a point preceding the pump inlet.

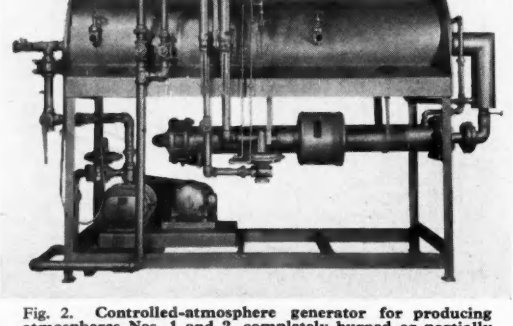


Fig. 2. **Controlled-atmosphere generator for producing atmospheres Nos. 1 and 2, completely burned or partially burned fuel gas; Equipment A.**

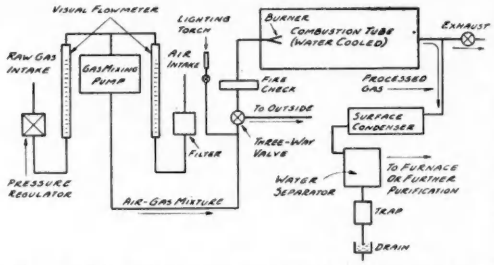


Fig. 3. **Schematic arrangement and flow diagram of gas generator for producing atmospheres Nos. 1 and 2, completely burned or partially burned fuel gas; Equipment A.**

The pump moves the air and gas mixture through the piping system to the fire-check and burner. The temperature of the combustion tube is sufficiently high to ignite the mixture whose combustion is carried quickly to completion in a catalyst filled refractory bed. This arrangement also ensures thorough reaction so that all traces of oxygen are removed. No outside heat is supplied to the combustion tube since its temperature is maintained by the net heat of combustion. The moisture from the products of combustion leaving the exit side of the combustion tube is condensed out of the gas in a surface condenser and separated from the gas in a water separator and a trap. The gas then may be either used in a furnace or further purified before using by drying, scrubbing out CO_2 or removing small amounts of sulphur.

The gas leaving the water separator is usually saturated with water vapour at a temperature about 10 to 15 deg. F. higher than the cooling water used in the surface condenser.

Atmosphere No. 1-A—Completely Burned Fuel Gas with CO_2 and H_2O Removed.

The reaction required to produce this gas is exactly the same as that outlined for gas No. 1. In this instance, however, the carbon dioxide and the water vapour are completely removed by separate apparatus used in conjunction with the generator described under atmosphere No. 1.

Using methane for the base fuel, a typical composition of this gas would be as follows: CO_2=0 per cent., CO=$\frac{1}{2}$ per cent., H_2=$\frac{1}{2}$ per cent., O_2=0 per cent., CH_4=0 per cent, N_2=99 per cent. Dewpoint, —60 deg. F. This gas is inert because of its extremely high nitrogen content. A variation of this composition which is usually somewhat more applicable to commercial furnace conditions consists of CO_2=0 per cent., CO=3 per cent, H_2=3 per cent, O_2=0 per cent, CH_4=trace, N_2=94 per cent. The gas is still inert but has enough active constituents to overcome oxidizing impurities which enter into the usual furnace application.

This gas is produced at a cost of approximately $·20 to $·40 per 1000 cu. ft. The range in cost is due to the difference between costs of electricity and steam when used for re-activating the carbon dioxide removal system and the drying system.

Equipment B.—Equipment required to produce this atmosphere consists of a generator the same as that shown in Fig. 2. The gas passes from this unit to the carbon dioxide removal system and the gas is further dried by means of a combination of refrigerant,

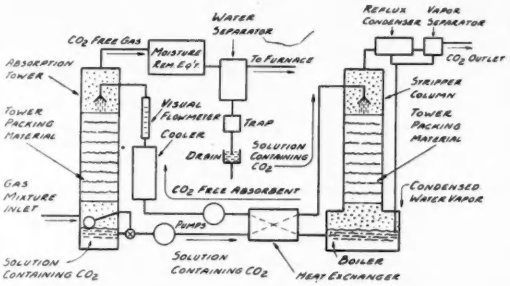


Fig. 4. **Schematic arrangement and flow diagram of carbon-dioxyde removal system for producing atmospheres Nos. 1-A and 2-A; Epuipment B.**

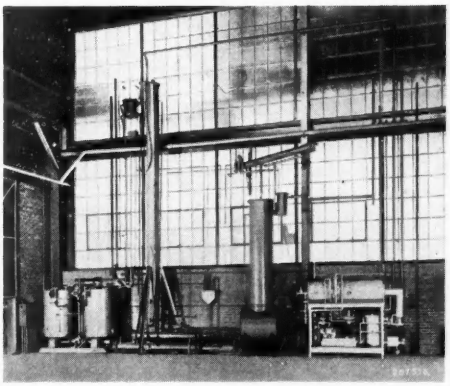


Fig. 5. **Complete gas equipment sequence for producing atmospheres Nos. 1-A and 2-A.**

and activated alumina drying equipment described separately.

Figs. 4 and 5 show the carbon dioxide removal system. The gas from the generator passes through the absorption tower through special packing material and gives up its carbon dioxide to the liquid which enters at the top of the tower and which trickles down through the packing material. The gas, free of carbon dioxide, collects at the top of the tower and flows through moisture removal equipment into the further drying equipment. The remainder of the system consists of a recirculating liquid system which is used to absorb the carbon dioxide and later be heated up to a point where the carbon dioxide may be driven off. The liquid which is saturated with carbon dioxide collects at the bottom of the stripper column. The liquid trickles down through packing material through which is passing heated steam rising from a boiler located at the base of the stripper column. During this passage the carbon dioxide is driven off and is passed through the top of the tower into a condenser which returns most of the heated steam back to the boiler. The carbon dioxide gas is discharged to the atmosphere. The absorbing liquid which has collected in the bottom of the column is pumped back again to the top of the absorption tower through the heat exchanger and cooler.

Atmosphere No. 2—Partially Burned Fuel Gas.

This atmosphere is similar to atmosphere No. 1 except that air to gas ratio is smaller and hence products of combustion contain appreciable CO and H_2. Sufficient heat is generated to keep these reducing gases forming without adding external heat, but heat generated is considerably less than for atmosphere No. 1. See Fig. 1. For this reason, the gas generating equipment is not self starting but must first be thoroughly heated up by operating the unit at a lean air to gas ratio. After the unit is heated the mixture may be made rich enough to produce atmosphere No. 2 since there is sufficient heat generated to maintain temperature but not heat up the equipment from a cold start. With methane as the fuel the following is a typical reaction at 6 to 1 air to gas ratio:

$$CH_4 + 1{\cdot}2\ O_2 + 4{\cdot}5\ N_2 \rightarrow 1/3\ CO_2 + 2/3\ CO + H_2 + H_2O + 4{\cdot}5\ N_2$$

For a given air to gas ratio, the amount of H_2 compared to H_2O and the amount of CO compared to CO_2 will vary with the design of equipment used. Efficient catalysts will give higher H_2 and CO and therefore higher reducing properties.

Using a fuel containing practically all methane a typical composition of this atmosphere would be as follows at a ratio of 6 parts of air to one part of gas: CO_2=5 per cent, CO=10 per cent, H_2=15 per cent, CH_4=1 per cent, N_2=69 per cent, O_2=0 per cent. Dewpoint of gas corresponds to approximately saturation at room temperature conditions unless auxiliary drying equipment is used. In many applications of this atmosphere, it is desirable to dry the gas to dewpoints of approximately 40 deg. F by using refrigerant dryer equipment illustrated in Fig. 8.

In general, this atmosphere is combustible and therefore air should be thoroughly purged out from any enclosures in which it might be used. Due to its relatively high nitrogen content and correspondingly low B.T.U. content it is not as highly combustible as raw fuel gases, but precautions against creation of explosive mixtures with air should always be taken when handling this gas. Also, any leakage of this gas from furnace openings, etc., should be carried away in efficient ventilation systems because the CO content makes it very toxic. In a great many applications the gas is burned as it issues from the furnace openings so that harmful CO is converted to comparatively harmless CO_2.

Cost of producing this atmosphere differs from that of atmosphere No. 1 in that more raw fuel gas is used. Average costs are from $.10 to $.12 per 1000 cu. ft.

Equipment A.—The gas generating equipment and comments on operation given for atmosphere No. 1 also apply exactly to atmosphere No. 2. See Figs. 2 and 3.

Atmosphere No. 2-A—Partially Burned Fuel Gas with CO_2 and H_2O Removed.

This atmosphere is the same as atmosphere No. 2 except with CO_2 and H_2O removed. The gas is produced using the same equipment and reaction described for atmosphere No. 1-A. The only difference consists in operating the primary gas generator at a ratio of air to gas which is richer so as to be able to produce the higher reducing properties in the gas.

Atmosphere No. 3—Partially Reacted or Cracked Fuel Gas.

Referring to Fig. 1, the left-hand portion of the curves show a region between ratios of 5 to 1 and ratios of 2½ to 1 where CO_2 and H_2O are decreasing toward zero and CO and H_2 are increasing to their maximum values. Atmosphere No. 3 is defined to fall in this region which in general is the region between atmosphere No. 2 which is partially burned fuel gas with some heat generated and atmosphere No. 4 which is completely reacted fuel gas where heat is required. At 3 to 1 ratio using methane, a typical raction is:

$$CH_4 + {\cdot}625\ O_2 + 2{\cdot}37\ N_2 \rightarrow {\cdot}052\ CO_2 + {\cdot}948\ CO + 1{\cdot}8\ H_2 + 2\ H_2O + 2{\cdot}37\ N_2.$$

Based on the above a typical analysis of this atmos-

phere would be as follows at a ratio of 3 to 1 : CO_2=1 per cent, CO=18 per cent, H_2=34 per cent, CH_4=1 per cent, O_2=0 per cent, N_2=46 per cent.

This gas requires some external heat to promote the reactions at a high temperature level. Assuming electricity as the means for supplying this heat, the cost is approximately $·15 to $·20 per 1000 cu. ft. depending on actual air to gas ratios used.

Equipment C.—Fig. 3 applies directly to this equipment, the only difference being that the combustion chamber is replaced with an electrically heated catalyst-filled retort chamber. All other auxiliaries are the same.

Atmosphere No. 4—Completely Reacted Fuel Gas.

This gas is produced from the complete reaction of fuel gas with the proper amount of air to produce an end product consisting of only carbon monoxide and hydrogen and nitrogen from the air. The reaction may be written as follows :

$$2CH_4 + O_2 + 4N_2 \longrightarrow 2CO + 4H_2 + 4N_2$$

This gas corresponds to the extreme left-hand range on the curve, Fig. 1. The carbon dioxide and water vapour are negligible in this range. External heating is required to produce this gas. Using a fuel gas containing practically all methane, a typical composition of the gas would be as follows : CO_2=0 per cent, CO=19 per cent, H_2=40 per cent, CH_4=1 per cent, N_2=40 per cent. The dewpoint of this gas would be of the order of minus 15 deg. F. The cost of producing this atmosphere using methane as the base fuel is approximately $·18 to $·25 per 1000 cu. ft.

Equipment C.—Fig. 3 applies also to this equipment, the only difference being that the combustion chamber is replaced with an electrically heated catalyst-filled retort. All other auxiliaries are the same. This equipment is the same as for atmosphere No. 3. The only difference is in the operation which requires a richer air to gas ratio.

Atmosphere No. 5—Dissociated Ammonia.

This gas is produced by the cracking of anhydrous ammonia. This gives a gas very high in hydrogen and with very low dewpoint.

When the ammonia is thoroughly cracked the composition consists of 75 per cent hydrogen and 25 per cent nitrogen and the dewpoint is below —60 deg. F. The gas is produced at a cost of approximately $4 per 1000 cu. ft. using ammonia in the standard small-size containers. This cost can be cut to approximately half of this value by using tank car quantities of ammonia. Approximately 22·1 lbs. of ammonia are required to produce 1000 cu. ft. of the dissociated gas.

Equipment D.—The equipment for producing this gas is shown in the photograph Fig. 6. It consists principally of an electrically heated catalyst-filled retort chamber through which passes the vapourized anhydrous ammonia.

Atmosphere No. 6—Partially Burned Dissociated Ammonia.

This gas is produced by mixing a limited amount of air with dissociated ammonia to produce a pure mixture of hydrogen and nitrogen using a lower hydrogen content than that obtainable with dissociated ammonia. Any proportion of hydrogen compared to nitrogen can be obtained depending on the amount of air mixed with the dissociated ammonia before burning.

A typical composition of this gas is as follows : H_2=20 per cent, O_2=0 per cent, N_2=80 per cent. Dewpoint corresponds to room temperature conditions unless auxiliary drying equipment similar to that described under atmosphere No. 2 is used.

A gas containing 20 per cent hydrogen could be produced for approximately $2·60 a thousand, based on small tank quantities of ammonia. This cost would

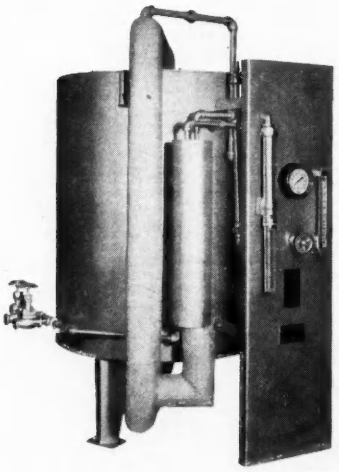


Fig. 6. **Equipment D for producing atmosphere No. 5, dissociated ammonia.**

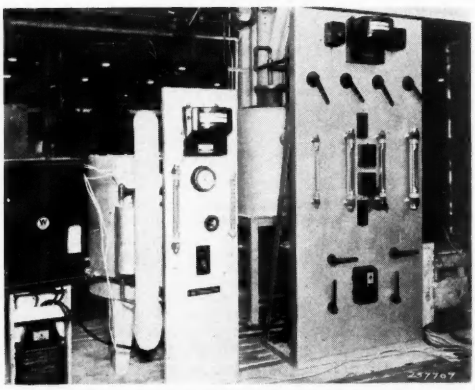


Fig. 7. **Equipment E for producing atmospheres Nos. 6 and 6-A, partially or completely burned dissociated ammonia.**

be approximately half if tank car ammonia were used.

Equipment E.—This equipment is shown in Fig. 7. It consists of two principal parts, the ammonia dissociator such as that described for atmosphere No. 7 and an additional retort chamber used to combust the mixture of air and dissociated ammonia. An advantage of this equipment is that any proportion of hydrogen compared to nitrogen can be produced up to the limits of dissociated ammonia itself. The equipment is also capable of operating at low turn-down values so that no gas is wasted in the process. This is desirable particularly since this gas is much more expensive than the average fuel gas.

Atmosphere No. 6-A—Completely Burned Dissociated Ammonia.

This gas is produced by the complete combustion of a mixture of air and dissociated ammonia. A slight deficiency of air is used so that no oxygen results from the combustion process.

This gas consists of a very pure mixture of 99 per cent nitrogen and 1 per cent hydrogen. Oxygen=0 per cent. Dewpoint corresponds to room temperature

conditions and further drying must be used if the application requires it.

This gas may be produced at approximately $2·40 per 1000 cu. ft. based on small quantities of ammonia or approximately half of this, based on using ammonia from tank cars. The equipment for producing this atmosphere is exactly the same as that described for atmosphere No. 6.

Auxiliary Equipment for Drying Atmosphere Gases.

In many applications of atmosphere No. 1 and No. 2 and also of other types of atmospheres, it is necessary to dry the gas to lower dewpoints than those obtained from equipment cooled with normal commercial

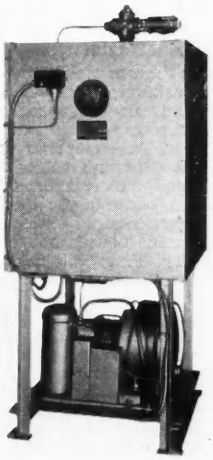


Fig. 8. **Equipment F for partially drying gas atmospheres by refrigeration to 40 deg. F. dewpoint.**

sources of cooling water. Dewpoints of approximately 40 deg. F. can be obtained from cooling the gas by means of refrigerant dryer equipment shown in Fig. 8. The atmosphere gas passes through a system of baffled finned type cooling coils inside a gas tight cabinet. A hermetically sealed refrigerating compressor unit moves refrigerant through the cooling coils. This will be designated as Equipment F.

When it is necessary to dry the gas to lower dewpoints an activated alumina dryer is used. This is shown in Fig. 9. It consists of a dual tower arrangement containing activated alumina for absorbing mixture from the controlled atmosphere gas. The purpose of the dual arrangement is to provide continuous gas drying while one tower is being reactivated to remove absorbed moisture. This equipment will dry gases to dew points below —60 deg. F. if necessary. This will be designated as Equipment G.

It may be useful to summarize the equipment combinations necessary to produce the controlled atmospheres described above.

To produce atmosphere No. 1 (completely burned fuel gas) use Equipment A or (A and F) set for complete combustion of fuel gas slightly on the reducing side.

To produce atmosphere No. 1-A (completely burned fuel gas with CO_2 and H_2O removed) use Equipment A plus equipments B, F and G.

To produce atmosphere No. 2 (partially burned fuel gas) use Equipment A or (A and F) set for incomplete or partial combustion but not lower than about 55 to 60 per cent of perfect combustion so that sufficient heat will be evolved within the generator itself to keep it going.

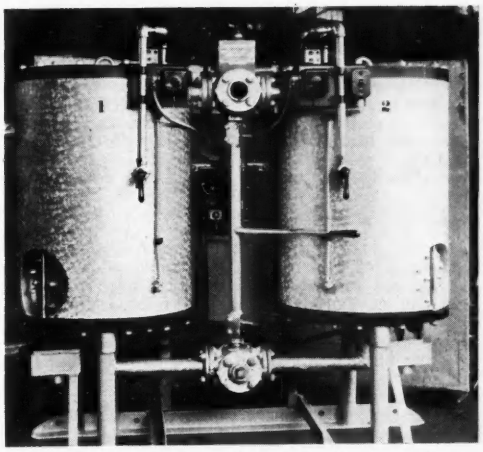


Fig. 9. **Equipment G; activated-alumina dryer for removing completely moisture from gas atmospheres.**

To produce atmosphere No. 2-A (partially burned fuel gas with CO_2 and H_2O removed) use Equipments A plus Equipments B, F and G.

To produce atmosphere No. 3 (partially reacted fuel gas) use Equipment C.

To produce atmosphere No. 4 (completely reacted fuel gas) use Equipment C.

To produce atmosphere No. 5 (dissociated ammonia) use Equipment D.

To produce atmosphere No. 6 (partially burned dissociated ammonia) use Equipment E plus F and G if drying is required.

To produce atmosphere No. 6-A (completely burned dissociated ammonia) use Equipment E plus F and G if drying is required.

Furnace Equipment to be Used with Controlled Atmosphere.

In general, all furnace equipment must be individually analysed and designed for the particular application of controlled atmosphere required. Atmosphere furnaces are fabricated to be gas tight. Many schemes are used to minimize the consumption of prepared atmosphere and to ensure positive control of atmosphere flow or circulation inside the furnace structure. When fuel fired furnaces are used, radiant tubes or muffles are necessary to keep the products of combustion from mixing with the prepared atmospheres. Electric furnaces of the type using resistors may be used without muffles where other factors in the application permit it. The remaining discussion deals with the applications of the various atmospheres, which have been outlined to various metal processes particularly those related to annealing, hardening, tempering and brazing of both non-ferrous and ferrous metals. No single atmosphere will be universally applicable to all processes related to the heating of metals. The closest approach to a universal heat treating atmosphere is 1-A which consists of a high nitrogen bearing gas which is oxygen free and which contains sufficient reducing properties to overcome effect of impurities from the metal being treated and from the brickwork of furnaces in which the metal is treated. The equipment necessary to produce this atmosphere is more expensive than that required for alternate choices of atmosphere which are suitable for a given process and which require less expensive equipment.

The problem in applying controlled atmospheres to metals usually resolves itself into partial or total pre-

vention of oxidation of the metal surfaces and prevention of metallurgical changes in metal such as loss of carbon from steel surfaces (decarburization). In some processes the atmosphere is applied to purposely affect the metal structure and composition such as gas carburizing where controlled amounts of carbon are added to the steel surface by means of chemical reaction between the metal and the atmosphere surrounding the metal.

ANNEALING.

Non-Ferrous Metals.

Copper may be annealed without oxidation in an atmosphere of steam but this method allows water staining and in many modern installations on wire, strip and tubing, particularly on finish-annealing it has been more desirable to use separately controlled atmospheres. Shiny bright surfaces can be obtained by using atmosphere No. 1 (completely burned fuel gas, slightly on reducing side).

Copper is discoloured at elevated temperatures in the presence of extremely small amounts of sulphur compounds, particularly hydrogen sulphide. Manufactured fuel gases such as coke-oven gas or carburetted water gas are usually passed through iron-oxide boxes to remove hydrogen sulphide, before being used commercially. This scrubbing operation usually removes hydrogen sulphide to a very small value of 5 grains per 100 cu. ft. of raw gas. Even though this amount is very small it is sufficient to discolour copper after mixing with air and burning in a gas generator. For this reason further removal is necessary beyond the gas generator. Complete combustion of the gases in the generator tends to convert most of the sulphur in the fuel gas both organic and inorganic into sulphur dioxide which is carried off in the condensate from the gas generator. The small amounts of hydrogen sulphide are removed by iron-oxide towers on exit side of gas generator.

Certain types of copper contain small amounts of oxygen which can react with hydrogen in the controlled atmosphere and cause embrittlement. In these cases the atmosphere must be set for a bare minimum of hydrogen and carbon monoxide (about ½ to ¾ per cent of each) without any free oxygen.

Copper Nickel Alloys may be bright annealed with same atmosphere as that used for copper (Atmosphere No. 1) and the atmosphere must be entirely free of sulphur. Hydrogen embrittlement in general is not a problem in the case of these alloys so that atmospheres with higher hydrogen and carbon monoxide contents may be satisfactorily used.

Copper-Zinc Alloys (*Brasses*) may be clean-annealed with some atmosphere as used for copper (Atmosphere No. 1). Bright-annealing is not obtained due to volatilization of zinc from the surface of material at elevated temperature. This gives surface a " clouded " appearance. Volatilization of zinc and subsequent oxidation on the surface of the metal by CO_2 and H_2O in the controlled atmosphere can be greatly retarded by using high nitrogen atmosphere from which CO_2 and H_2O have been removed. (Atmosphere No. 1-A).

Copper-Silver Alloys may be bright-annealed with high nitrogen atmosphere free from CO_2 and H_2O (Atmosphere No. 1-A) as well as being entirely free from traces of sulphur.

Copper-Silver Alloys may be bright-annealed with either atmospheres No. 1 or No. 2 but must be absolutely free of any traces of sulphur or discolouration will occur.

Nickel and Monel Metal may be bright-annealed with either atmosphere No. 1 or No. 2 but must be entirely free of sulphur. The metal surfaces, although free of oxide, present a grey or matte finish. Shiny bright surfaces can be obtained by using dissociated ammonia (atmosphere No. 5) or with combusted dissociated ammonia (atmospheres No. 6 and 6-A). Iconel which is a high nickel bearing alloy with chromium and iron can only be bright-annealed in atmospheres No. 5, 6, 6-A.

Aluminium and its Alloys can be successfully treated in air atmospheres provided moisture content is relatively low. Completely burned or partially burned and partially dried fuel gases (atmospheres No. 1 and No. 2) can also be successfully used. In this field there is not yet any widespread demand for application of separately prepared controlled atmospheres since prevention of slight surface oxidation is not a serious problem.

Magnesium can be annealed using atmosphere No. 1 which in general prevents any active or rapid oxidation, and thus allows safety against possible combustion of the magnesium at the normal heat treating temperatures. Air atmospheres with ½ to 1 per cent of sulphur dioxide added are also successfully used.

Ferrous Metals.

Low Carbon Steel may be bright-annealed, using partially burned fuel gas with generator set to give maximum reducing properties (atmosphere No. 2). In those cases where the available cooling water is over 60 deg. F. in temperature the dewpoint of the gas atmosphere leaving the generator will be over 70 deg. F. In general, atmosphere No. 2 with dewpoints of over 70 deg. F. can cause discolouration of steel due to oxidizing action of excess water vapour as the steel slowly cools down through a temperature range from 1100 deg. F. to 700 deg. F. In those cases where cold water is not available the year round it is necessary to supplement the atmosphere with partial drying to dewpoints of about 40 deg. F. Atmosphere No. 2 is approximately in equilibrium with low carbon steels at normal annealing temperatures and hence there is no measurable amount of carbon loss or gain from the steel due to chemical combination with the atmosphere surrounding it. This atmosphere is very definitely decarburizing to medium and high carbon steels and to various alloy steels, and should not be used where decarburization cannot be tolerated.

Medium and High Carbon Steels can be bright-annealed using atmosphere No. 1-A. This atmosphere is not decarburizing and is practically neutral to a wide range of carbon contents in the steel so that neither carburization or decarburization takes place. The small amounts of CO and H_2 in the atmosphere are sufficient to react with small amounts of oxidizing impurities on the steel being heated, or react with impurities from furnace brickwork. Long-cycle annealing of alloy carbon steels or high carbon steels requires an atmosphere that is chemically inactive and which therefore does not react with the carbon in the steel. The high nitrogen content of atmosphere No. 1-A combined with total removal of decarburizing components such as CO_2 and H_2O results in an atmosphere which is chemically " neutral " and reaction rates with the carbon in the steel are so small that no measurable gain or loss of carbon from steel occurs when steel is heated to annealing temperature and held there for long periods of time.

Alloy Carbon Steels—Tool Steels and High Speed Steels may be annealed on long cycles without oxidation or decarburization using atmosphere No. 1-A. Atmosphere requirements are the same as those discussed above for high carbon steels.

Stainless Steels, including the chrome-nickel-iron alloys and the chrome-iron alloys, can be annealed without heavy oxidation in atmospheres No. 1, and No. 2, and very little oxidation in atmosphere Nos. 1-A. 2-A, 3, and 4. However, if it is desired to bright-anneal these steels it is necessary to use pure dry hydrogen. Immeasurably small amounts of oxygen must be absent from the gas atmosphere, and the bright-annealing to be successful must be done in alloy-

steel muffles constructed so that the pure dry atmosphere is maintained without possibility of entrance of the least traces of any oxygen bearing gases such as O_2, CO_2, CO, H_2O. Atmosphere No. 5 (dissociated ammonia will be suitable. Atmospheres Nos. 6 and 6-A are also suitable provided they are produced from equipment which eliminates all traces of oxygen and water vapour.

Hardening of Ferrous Metals.

In production finished machined parts of all sizes and descriptions can now be hardened free from oxidation and decarburization. This development is of great significance since uniform quality of work on a large production basis can be realized without subjecting the pieces to further machining, grinding, sand blasting, pickling or other expensive cleaning operations which formerly were necessary to eliminate scale and soft skin (decarburization) on the work being heat treated. The atmosphere required to accomplish bright-hardening without decarburization must be very low in CO_2 and water vapour. Atmospheres 1-A and 2-A meet these requirements. However, it is possible to produce an atmosphere which has only very small residual amounts of CO_2 and water vapour by completely reacting the hydrocarbon in the gas to CO and H_2 with a limited amount of air in the presence of a catalyst at high temperature. This is represented by atmosphere No. 4. A variation of this, where the cracking is not quite so complete, is represented by atmosphere No. 3.

Atmosphere No. 3 is suitable for short-cycle (less than 2 hours) hardening of medium carbon steels at medium range hardening temperatures (1400-1450 deg. F.) with no oxidation or decarburization.

Atmosphere No. 4 is suitable for hardening of high carbon steels and alloy carbon steels without oxidation as decarburization. This gas contains no CO_2 and very little water vapour, is non-decarburizing to high carbon steels and is particularly applicable to hardening where decarburization cannot be tolerated. This gas can also be set so as to be in " carbon balance " with the steel being heat treated so that neither carburizing nor decarburizing takes place. Fig. 10 shows an instrument which has been developed for predicting the approximate carbon content of the steel at which the surrounding atmosphere is in equilibrium. This instrument is known as a " hot wire gauge " and operates on the principle of a measurement of the change in resistance of a low carbon steel wire carburized with the surrounding gas atmosphere. The wire is heated by electric current inside a glass tube and is surrounded by the atmosphere being tested. The heated wire absorbs carbon from the gas until it is in equilibrium with the surrounding gas. This process takes place very quickly because of the small cross section of the wire. A change in resistance measured on a potentiometer is calibrated in terms of the carbon content at which the particular gas is in equilibrium with the steel being heat treated. This instrument is useful on applications where it is desirable to maintain an atmosphere which is in approximate chemical balance with the carbon content of the steel being hardened so that the steel surface is neither carburized or decarburized. Atmosphere No. 4 may be produced to give these conditions.

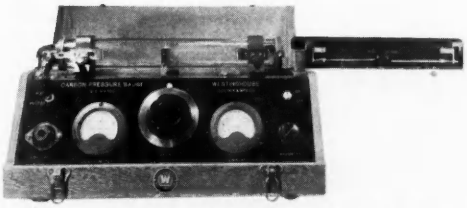


Fig. 10. **Hot-wire gauge for determining carburizing power of gas atmosphere.**

Tool steels and high speed steels can be successfully hardened without oxidation or decarburization using atmosphere No. 4. The high-carbon high-chromium tool steels can be hardened without decarburization, but will be tarnished due to slight oxidation of the chromium. If it is desired to bright harden these steels it is necessary to use atmosphere No. 5 (dissociated ammonia) inside a special design of alloy metal muffle furnace.

Gas Carburizing.

In addition to the developments of controlled atmosphere for prevention of oxidation and decarburization, it is possible to control the rates at which carbon is added to the surface of steel and the distribution and depth through which the carbon disperses into the steel. As stated above those gases which contain no CO_2 or water vapour will not remove carbon from steel. A gas with no CO_2 or H_2O vapour is an excellent atmosphere to use as a " base " for adding carbon-bearing gases which will react to add carbon to the steel. With an efficient " base " or " carrier " gas the amount of carbon-bearing gases which must be added to produce fast soot-free carburizing is relatively small. Methane is by far the most efficient carburizing gas and small amounts of methane added to a " carrier " gas containing no CO_2 or water vapour produces a gas very suitable for quick efficient soot-free carburizing. Atmosphere No. 4 is a very efficient " base " or " carrier " gas. This gas as normally produced has no CO_2 and very small water vapour content. Due to the presence of CO, H_2 and residual methane in the gas as produced, it already possesses a reasonable carburizing " potential " and the addition of one or two per cent of methane gives a very active gas for carburizing.

Successful application of these atmospheres for quick clean gas carburizing also requires the use of such atmospheres in furnace equipment which will successfully maintain these atmospheres. Equipment which allows oxygen from the air to infiltrate even in small amounts will destroy the carburizing " potential " of the gas and efficient soot-free gas carburizing is not possible.

ATMOSPHERE FURNACE BRAZING.

Non-Ferrous Metals.

Many non-ferrous metals can be brazed in protective furnace atmospheres. Copper and copper alloys are brazed using "Phos-Copper" or "Ez—Flow," "Sil-fos" and similar alloys for brazing material. Atmosphere No. 1 is suitable for a great many of these applications. If discolouration is to be prevented all traces of sulphur in the gas must be removed as in the case of bright-annealing copper. Richer gas atmospheres with higher reducing properties are also suitable, such as atmospheres Nos. 2, 3, and 4, where hydrogen embrittlement is not a factor.

Ferrous Metal Brazing.

Brazing of steels with copper at 2050 deg. F. is a widely used method of joining all types of assemblies. Silver brazing of steels at lower temperatures such as 1700-1800 deg. F. is finding growing applications. In both instances reducing atmospheres are required. Atmosphere No. 2 (partially burned fuel gas) is applicable

when the brazing does not require prevention of decarburization. This is not a problem on low carbon steels but may be a factor to contend with in medium and high carbon steels. Although the average brazing operation requires only a relatively short time at the high temperature, the rates of decarburization are also very rapid at these high temperatures when appreciable CO_2 and water vapour are present such as in atmosphere No. 2.

Where decarburization of the brazed work is to be prevented atmosphere No. 2-A or atmosphere No. 4 should be used. Atmosphere No. 4 is particularly suitable for brazing because the high H_2 and CO content give it very high reducing properties which in general are very desirable for brazing ferrous metals.

Stainless steels and the high-chromium steels require an extremely pure reducing atmosphere. Atmosphere No. 5 is the most suitable, as well as dry, oxygen-free hydrogen.

Sintering or Powder Metallurgy Applications.

Controlled atmospheres are necessary in the production of metals and alloys in this rapidly growing field. Brasses—bronzes, etc., are sintered with reducing atmospheres such as atmospheres No. 2, No. 3 and No. 4.

Ferrous alloys and iron, in general, utilise these same atmospheres. Atmospheres No. 3 and No. 4 are particularly useful because of their very high reducing properties.

As in normal ferrous metallurgy these are problems where decarburization must be prevented. Fuel gas atmospheres very low in CO_2 and water vapour are desirable. Atmospheres No. 2-A and No. 4 fulfil these requirements.

In those cases where oxidation of chrome (such as stainless steels) must be prevented, the pure dry hydrogen and dry hydrogen-nitrogen mixtures must be used. Atmosphere No. 5 (dissociated ammonia) fulfills these requirements.

A summary of the applications of atmospheres to various metals and metal processes is given in the following table.

In conclusion it may be said the field of application of separately prepared controlled atmospheres will continue to expand. As a result of developments in this field many heat treating processes can be controlled with high precision, quality is improved and is uniform, and large savings result because of elimination of cleaning, finish-machining and grinding, etc. In parallel with the development of controlled atmospheres, the heat treating process equipment in which these atmospheres are used has been developed, to use these gases properly. The best controlled atmosphere is useless unless the companion equipment in which the metal is processed is designed so as to hold and maintain properly the atmosphere composition which is brought to it.

Hence, continued development, refinement and improvement of heat treating equipment is necessary in order to realize fully the benefits of the application of the separately prepared atmosphere.

ATMOSPHERES SUITABLE FOR HEAT-TREATMENT OF DIFFERENT METALS.

Material processed.	Process.	Temp. range deg. F.	Time cycle ("Long" if) over 2 hr.	Required surface	Atmospheres which will give desired results.	Atmospheres commonly used.
Bright or Clean Annealing.						
Low carbon steels	Anneal.	1200 to 1350	Long	Bright	1A, 2, 2A, 5, 6, 6A	2
Medium carbon steels	Anneal (no decarburization)	1200 to 1450	Long	Bright	1A, 2A, 5, 6, 6A	1A
High carbon steels	Anneal (no decarburization)	1200 to 1450	Long	Bright	1A, 2A, 5, 6, 6A	1A
Alloy steels, medium & high carbon	Anneal (no decarburization)	1300 to 1600	Long	Bright or Clean	1A, 2A, 5, 6, 6A	1A, 2A
High-speed tool-steels including molybdenum high speeds.	Anneal (no decarburization)	1400 to 1600	Long	Bright or Clean	1A, 2A, 5, 6, 6A	1A
Stainless steels, chromium & nickel chromium.	Anneal	1800 to 2100	Short & Long	Bright	5	5
High silicon steel, electrical sheet	Anneal	1900 to 2000	Long	Clean	1A, 6	1A, 6
Copper	Anneal	400 to 1200	Long or Short	Bright	1	1
Various brasses	Anneal	800 to 1350	Long or Short	Clean	1	1
Copper-nickel alloys	Anneal	800 to 1400	Long or Short	Bright	1A, 6	1A
Silicon-copper alloys	Anneal	1200 to 1400	Long or Short	Bright	1A	1A
Nickel	Anneal	1600 to 2000	Long or Short	Bright	1, 1A, 2, 2A, 5, 6, 6A	1,5
Automatic Brazing or Soldering Operations.						
Low carbon steels	Copper brazing	2050	Short	Bright	2, 2A, 4, 5, 6	2
Medium & high carbon steels	Copper brazing (no decarburization)	2050	Short	Bright	2A, 4, 5, 6	4
Alloy steels, medium & high carbon	Copper brazing (no decarburization)	2050	Short	Bright	2A, 4, 5, 6	4
High carbon, high chromium steels	Copper brazing	2050	Short	Bright	5	5
Stainless steels	Copper brazing	2050	Short	Bright	5	5
Copper or brass	Phos-copper brazing or silver soldering	1500 to 1600	Short	Bright	1	1
Bright Hardening and Tempering.						
Medium carbon steels	Hardening	1400 to 1600	Short	Bright or Clean	1A, 2A, 4, 5, 6, 6A	4
High carbon steels	Hardening	1400 to 1800	Short	Bright or Clean	1A, 2A, 4, 5, 6, 6A	4
Alloy steels, med. & high carbon	Hardening	1400 to 1800	Short	Bright or Clean	1A, 2A, 4, 5, 6, 6A	4
High-speed tool-steels, including molybdenum.	Hardening	1800 to 2400	Short	Bright or Clean	1A, 2A, 4, 5, 6, 6A	4
All classes of ferrous metals	Tempering or drawing	400 to 1200	Short	Bright or Clean	1A, 2	2

TRENDS IN ORGANIC PLASTICS.

By JOHN DELMONTE, Technical Director, Plastics Industries Technical Institute.

THE wartime developments in organic plastics have been marked by the origin of new plastics, new processing methods, and new and unusual applications. While the main purpose of these trends has been directed towards the achievement of total victory in the war, they will contribute in no small measure to industrial pursuits. Perhaps one of the best indices of the utility and growth of plastics in the United States is the comparison of industrial activity in 1941 with 1944. The number of compression moulders increased from 400 to approximately 800; the number of injection moulders from 200 to 320; and the extruders reached a total of 112 companies in 1944. These statistics represent activities in only one phase of the plastics industry, and equally enlightening are the statistics on production of plastics materials which attained a total of 700,000,000 pounds in 1944. Compared with metals this figure appears small, but when measured against pre-war activities it indicates a pronounced trend upwards.

In analyzing the developments and trends in organic plastics during the war, it is possible to establish two main groups: (1) Improvements in existing materials and methods, and (2) Establishment of entirely new materials and fields of activities. The following summary emphasises the gains:

IMPROVEMENTS IN EXISTING MATERIALS

A. *Phenolics*. The demands for high impact strength phenolics brought forth cordfilled and sisal fibre filled materials to supplement the shredded fabric filled varieties. Equipments for the U.S. armed forces specified these materials quite frequently. Among the fillers, powdered metals came into prominence, particularly in the development of frangible bullets for target practice. In the field of cast phenolics, the colour problem was relegated to the background and attention given to the production of quick curing resins capable of forming large tools or blocks, some of which weighed close to 2000 lbs. Cast phenolic tools were extensively employed by various manufacturers as drill jigs, stretch press dies, contoured blocks for hydropress work, and innumerable operations where rapid duplication of contoured surfaces was important. Fig. 1 illustrates a typical cast phenolic plastic tooling. The speed of producing these tools and the many costly hours saved over the machining metal tools, made them highly acceptable for many operations.

Fig. 1. **Vega Plastic Tool Technique.**
The light stong plastic tools are well liked in the production departments. If drill jigs such as these were made of steel or even dural, they would be heavy and harder to handle.

In the field of adhesives high and low temperature setting phenolics were developed to fulfil the demands of the moulded plywood field. Most noteworthy was the introduction of resorcinol-formaldehyde on a commercial scale and its wide acceptance as a boil proof bonding agent. It was featured by a nearly neutral pH at the glue line, and quick development of very high shearing strengths in the cementing of wood.

Phenolic resins as well as other resins were developed for resin-ion exchangers, making possible the purification of various solutions. The phenolics were also employed with aldehyde modified polyvinyl alcohols to establish cross-linking and attain better thermosetting qualities for the polyvinyl resins. Interest and developments continued on lignin base moulding compounds modified with phenolics, though large scale applications of these modified forms failed to develop.

During the war, the major materials manufacturers devoted considerable time in obtaining basic engineering data on the various plastics, and much technical information is now available on the behaviour of plastics under various temperature and humidity extremes.

B. *Urea and Melamines*. At the commencement of the war, the melamine formaldehyde resins were beginning to attain considerable importance as a moulding material and as an adhesive. Their superior performace as an arc resisting material led to their wide scale application to ignition distributor housings (see Fig. 2) for high altitude aircraft. The superior temperature and moisture resistance of the melamine mineral filled materials allowed this compound to supersede urea-formaldehyde resins in a number of applications. Chief interest in the water soluble urea and melamine formaldehyde resins centred upon the adaptation of these materials to increasing the wet strength of paper (only 3 to 4 per cent will accomplish this); and in their adaptation to textile finishing problems. Their light colour and water solubility make them leading contenders in this new and growing industry.

C. *Cellulose Derivatives*. In examining the cellulose esters and ethers as a group, one will be impressed by the new applications brought about in these compounds, which entailed new formulations with larger proportions of plasticizer. Particular reference is made to strip-coatings developed from cellulose acetate-butyrate and from ethyl cellulose. These strip coatings were applied to delicate tool or machine parts from a hot-melt tank. The thick coatings which were formed protected the parts against mechanical abuse, and could be readily removed by stripping from the parts in question at the proper time. Even more outstanding were the applications of ethyl cellulose hot-melts to the production of tooling for aircraft purposes. The somewhat resilient thermoplastic formulation was tough enough to be employed in drop-hammer work, far outliving its lead predecessors. This is attributed to the resilient nature of the material and its low modulus of elasticity. In the manufacture of these thermoplastics toolings, hot-melts were poured at about 360 deg. F. to fill a metal die such as a zinc alloy base. Perfect matching of contours was realised on cooling. Clearance for the metals was possible by the rubber-like nature of the mass of plastic.

D. *Polyvinyl resins*. The transition from peace to war was marked by a cessation of the application of polyvinyl butyral as the plastic layer in automobile safety glass and its introduction as a waterproofing

Fig. 2. **Melmac Distributor Head and Finger with the Bendix Scintilla Aircraft Magneto DFLN-5 used in the liquid cooled aircraft engines for these planes.**

material for woven textile goods. Considerable success was enjoyed in this field, as well as that of substitute shoe soles. On the other hand, the polyvinyl chloride-acetate copolymer sheet, tough, resilient, and stable under wide temperature extremes found its way into many instruments and computing panels. Some use of the compound was made in binocular cases to resist mould and fungi attack which had ruined leather cases.

Considerable attention has been given in recent years to cloth coatings from the polyvinyl resins, and various emulsions which possessed high solids content were developed. Always a difficult material to dissolve in simple, low cost solvents, the emulsions give promise of extending the range of applications of these compounds. Other copolymers such as that of polyvinylidene chloride and polyvinyl chloride continued to expand in industrial importance and to the line of chemically resistant conduit was added a thin protective film which had a very high resistance to water vapour permeation. Cloth coatings and extruded filaments appeared from these resins. The thin films were widely used as protection for goods being shipped overseas.

E. *Acrylic Resins.* New developments in methyl methacrylate were marked by the development of improved heat resistance, raising the heat distortion point to the neighbourhood of 190 deg. F. Research still continued, with indifferent success, in developing a hard scratch resisting film to withstand abrasion. A laminated structure, developed for the B-29 bomber, comprised two faces of methol methacrylate and a core of polyvinyl butyral. Maximum resistance to shattering was possessed by this assembly at high altitude. Considerable work also was in progress upon the preparation of acrylic acid esters from lactic acid.

F. *Polystyrene.* High temperature resistant modified polystyrene compounds made their appearance during the war. This was attained by two new approaches—polydichlorostyrene and copolymers with divinyl benzene. These developments will mean the introduction of polystyrene as a moulding material capable of taking boiling water, and hence the probable appearance of these materials in numerous household articles. Styrene as a raw material for the production of butadiene-styrene copolymer was the outstanding synthetic rubber development. The tremendous production required of this copolymer (over 600,000 tons annually) increased the production capacity of styrene beyond that of any other plastic.

G. *Polyamide.* Textile applications of the polyamides were converted over to parachute requirements at the start of the war. However, the past few years also saw the development of moulding compounds which possessed unusual toughness and impact strength. This development is still in its early stages, though the higher temperature resistance of the polamides invites concentrated efforts to attain this goal in a moulding compound.

H. *Proteins.* Among the proteins, casein entered a new role during the war as a textile material. While the production of textiles from casein were first promulgated in Italy before the war, further research in the United States led to the unravelling of the protein molecules and the attainment of superior physical properties.

I. *Alkyds.* In the field of synthetic resin coatings, the alkyds became rather tight with decreased supplies of phthalic and maleic anhydrides. However, research continued with emphasis on " adduct " formation. One important " adduct " formed with cyclopentadiene found its way into wide usage as a waterproof coating material.

J. *Lightweight Foams.* Considerable interest has been evidenced in all thermoplastics and thermosetting materials in the preparation of lightweight foams. Expanded polystyrene foam, cellulose esters, synthetic rubbers, and phenolics have attracted much attention in sandwich construction for aircraft.

IMPROVEMENTS IN MACHINES AND METHODS.

The improvements in machines and methods reflect the developments in organic plastics. Most obvious machine improvements were in the moulding field. Outstanding was the development of units for injection moulding and extrusion of thermosetting compounds. These machines entered into commercial production of continuously extruded phenolics, one important application of which were the rocket launching tubes installed on aircraft. Extruded thermosetting materials show promise of entering into the building hardware field.

Among moulding machines and their accessories, the new developments in preheating methods have been particularly outstanding. High frequency preheating at 30 megacycles was applied to the preheating of many moulding compounds ; the time of the moulding cycle was reduced to less than one-third of normal in many instances. The improvements were more apparent the thicker the sections to be moulded. For the first time it became practical to compression or transfer mould sections of unlimited thickness. Preheating by high frequencies was generally accomplished in a minute or less and press closing time, total moulding pressure, and cure cycles were markedly reduced. One of the newer popular high frequency units is illustrated in Fig. 3. Every major moulder now lists as standard equipments high frequency preheaters. Before the war, there were none in wide scale commercial production. High frequency curing of glue lines in the laminating of timbers and plywood has also grown in industrial importance.

Latest designs in compression moulding presses reflect the trends toward transfer moulding, with hydraulic rams at the top and at the bottom of the press. One plunger clamps the mould while the other develops the moulding pressure. Among injection moulding machines, vertical plunger types have appeared to supplement the horizontal stroke machines. As much as 22 oz. per plasticizing cylinder was achieved

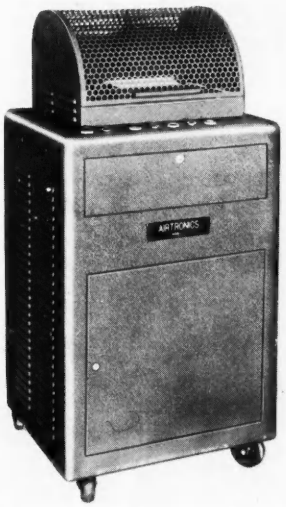


Fig. 3. **High-frequency preheating machine for moulding compounds.**

in the design of one model of injection moulding machine. Special plasticizing cylinders and nozzles have been developed for coping with the newer polyamide moulding compounds, while certain corrosion resistant steel cylinders were prepared for the injection moulding of some of the chlorinated polyvinyl resins.

Production machines have also been developed within the past two years for the blow moulding of thermoplastic materials. One approach is to form a comparison with an injection nozzle, and then expand this mass of material by internal gas pressure against the sides of the moulds. Attractive, lightweight bottles have been moulded in this manner. This phase of the industry is moving forward quite rapidly.

INTRODUCTION OF NEW MATERIALS.

A number of new plastics materials made their industrial appearance during the past few years. Some of these have been the subject of careful and organized research for many years, while others owe their origin to the appearance of new raw materials and chemical reactions.

A. *Polyesters.* A large number of new liquid and paste-like thermosetting materials, variously referred to as polyesters or unsaturated alkyds, made their appearance in recent years in the United States. Trade names such as " Columbia " resins, " Allymers," " Selectron," " Laminac," " XRS-16631," " Plaskon 911," " Thalids," and many others have made their appearance. In general these resins are prepared from unsaturated alcohols such as allyl alcohol, and polybasic acids, including various unsaturated members. The raw materials possess the elements necessary for cross-linking. Generally these polyesters are plasticized with some partially polymerized styrene or vinyl acetate.

The field of application of the polyester resins lies in the manufacture of transparent thermosetting sheets and in the production of low pressure or contact pressure laminates. Glass cloth has played a prominent role in the development of high strength members from the new thermosetting resins. Tensile strengths in excess of 100,000 lb. per sq. in. have been obtained.

B. *Silicones.* The commercial production of silicone resins has been underway for more than a year now. As temperature resisting materials these plastics have been outstanding. As binders for glass fabric they have already made notable contributions in the electric motor field, permitting much higher operating temperatures. The various oils and greases prepared from silicone resins have demonstrated unusually small changes of viscosity with temperature, behaving much more satisfactorily than petroleum base oils. The silicone resins generally start with silicon tetrafluoride which is reacted with various Grignard reagents. Direct synthesis of silicone resins has also been achieved by contacting alkyl halides with powdered silicon and copper catalysts at elevated temperatures.

C. *Polyethylene.* Still a relatively new material to the United States, commercial production of polyethylene was not under way until 1943. However, the applications of the materials, particularly as electrical insulation have been growing rapidly. The inherently good flexibility without plasticization makes this material one of the most promising plastics at temperature extremes. Excellent resistance is possessed by polyethylene to a wide variety of organic and inorganic chemicals.

D. *Furanes.* Commercial production of resins from furfural and furfuryl alcohol got under way during 1944. These low viscosity liquid resins proved to be highly valuable as adhesives for organic plastics and rubber products, developing exceptionally high bonding strengths. In addition, they served as liquid resin impregnants and were very useful in the application to plaster of Paris patterns and forms, hardening these to a strong, durable and temperature resistant structure.

E. *Miscellaneous.* Numerous miscellaneous materials began to make their industrial appearance. Included among these were various synthetic resins such as polyvinyl carbazole, resinous products from sulphur dioxide and olefines, tetrafluoreethylene, and various natural resins from rosin and rosin esters.

NEW FIELDS OF ACTIVITY.

In addition to the new materials which have been developed during the past few years, there have appeared new important fields of activity for the organic plastics. These represent activities outside of the conventional moulding, laminating, casting, and fabricating processes.

A. *Post Forming of Thermosetting Laminates.* The forming of thermosetting canvas base phenolic laminates attained a wide scale application in the production of numerous components such as ammunition boxes, chutes, hoppers, fairings, etc. The technique requires reheating the phenolic laminate at a temperature (400 to 500 deg. F.) far in excess of its laminating temperature. The material softens sufficiently to be formed and drawn to a limited extent. This method extends the possibilities of phenolic laminates from flat or tubular stock and their miscellaneous punchings to include many curved shapes. Luggage, refrigerator units, trays, etc., are some of the post-war articles being formed by this process. Some typical post formed thermosetting laminates are illustrated in Fig. 4. By these methods it was possible to introduce

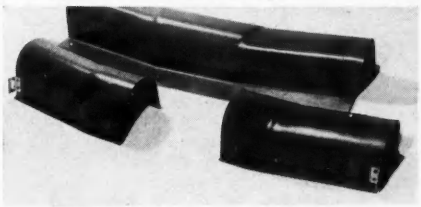


Fig. 4. **Post formed grade C laminates. Parts for B-17 bomber formed with plastic dies.**

beading or ribs to stiffen large flat panels of laminated stocks.

B. *Decorative Plywoods.* The preparation of decorative plywoods through the inclusion of high strength papers or coloured prints on the face of conventional plywood has opened up these materials to many new uses in the building industry. Thin sheets of melamine or phenolic impregnated materials are laminated to the face of the plywood at the same time the plywood is hot pressed. An attractive, integral assembly is completed which resembles a solid sheet of laminated plastics.

C. *Low Pressure Moulding and Laminating.* The techniques of low pressure moulding and laminating have formed a new phase of plastics activity. From contact pressure laminates such as radar housings or wing fairing, to droppable fuel tanks requiring cast metal dies and a rubber covered punch, low pressure methods are increasing their scope. Generally all pressures under 250 lb. per sq. in. are considered in this classification. Vacuum pressures alone suffice in some instances, while other operations require autoclaves. Low cost concrete, plaster, or wooden moulds were employed in many cases, though as the production requirements grew, greater investments were made in tooling costs. Glass fabrics were employed extensively in developing low pressure laminates.

D. *Impregnation of Plaster Forms.* An entirely new activity has commenced in the resin impregnation of finished plaster of Paris or "Hydrocal" forms and patterns. These inorganic materials are completely impregnated with resin and cured to hard durable structures, the physical properties of which are improved some 300 to 400 per cent Temperature and chemical resistance are vastly improved. Furane resin derivative proved to be the most popular in effecting the treatments, which are bound to have a broad influence on relationships between the ceramics and plaster industry.

E. *Composite Laminates.* The advent of new high strength adhesives has made possible the preparation of composite laminates of sheet metal to various woods and plastics, or combinations of various plastics with one another, or unusual assemblies involving rubber or low density expanded plastics. These unusual combinations of materials will increase the fields of application of plastics from a decorative and utilitarian point of view.

A STUDY OF THE THEORY OF AXIAL-FLOW PUMPS.

By G. F. WISLICENUS. (From *Transactions of the A.S.M.E.*, Vol. 67, No. 6, August, 1945, pp. 451-463.

EXISTING publications on the theory of axial-flow pumps or turbines show a sharp distinction between the classical or one-dimensional approach and the "airfoil" or two-dimensional approach to this problem. It is the principal aim of this paper to demonstrate that the results of these two methods of calculation are essentially the same, provided that certain well-established theoretical corrections are applied to the two-dimensional equations, in order to take into account the interaction of the vanes in the system.

The two-dimensional procedure is exemplified in Fig. 1, where the average relative velocity is defined as the vectorial mean between the incoming and the discharging flow, and is designated by v_∞. If L is the force-action normal to this average flow, then for unit span

$$L = C_L \frac{\rho v_\infty^2}{2} l \quad .. \quad .. \quad .. \quad (1)$$

From theory, confirmed by wind-tunnel data

$$C_L = 2 \pi \sin \alpha \quad .. \quad .. \quad (2)$$

where α is the angle of attack measured from the direction of zero lift.

For vanes which do not overlap, a sufficient approximation of the zero-lift direction can be obtained by drawing a straight line through the trailing edge and through the point A in Fig. 1. If the point of maximum camber lies in the leading half of the vane, this point A is the point of maximum camber, otherwise point A is to be located at the centre of the mean camber line of the vane.

If the vanes overlap, the leading part of the vane has less effect on the vane action than it would have if the vanes were widely spaced. This fact can be taken into account to some extent by drawing the zero lift line according to the simple rule exemplified in Fig. 2.

From the change of the peripheral momentum of the flow

$$L_U = \Delta V_U V_a \rho t \quad .. \quad .. \quad (3)$$

where L_U is the peripheral component of L for unit span.

It is seen that

$$L_U = L \frac{V_a}{v_\infty} \quad .. \quad .. \quad .. \quad (4)$$

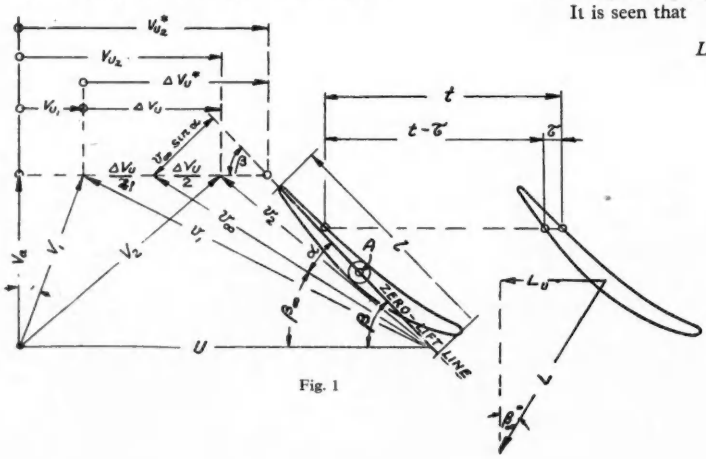


Fig. 1

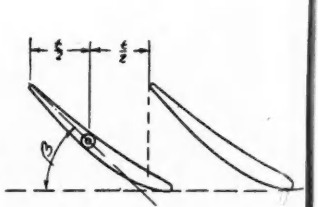


Fig. 2

consequently

$$C_L = \frac{2\,\Delta V_U}{v_\infty}\,\frac{t}{l} = 2\,\pi \sin\alpha \quad .. \quad .. \quad (5)$$

This equation relates the deflection ΔV_U to the average flow v_∞, to the ratio of vane spacing to vane length, $\frac{t}{l}$, and to the inclination α of the vane to the average relative flow.

Since only $\frac{t}{l}$ and α represent the form of the vane system, the latter may be replaced, hydraulically, by a system of straight and parallel vanes, related to the actual vane system, as shown in Figs. 1 and 2. With this simplification in mind, it is then possible to compare the two-dimensional theory, equation (5), with the one-dimensional assumption that the relative discharge velocity v_2 is parallel to this straight vane. The logical basis of the comparison is that the two theories must not give contradictory results. More specifically: the results of the two-dimensional theory must consistently approach those of the one-dimensional theory as $\frac{t}{l}$ approaches zero.

Here an apparently paradoxical situation is encountered. If equation (5) is rewritten in the form

$$\Delta V_U = v_\infty\,\pi \sin\alpha\,\frac{l}{t} \quad .. \quad .. \quad (6)$$

it is seen that for infinitely close vane spacing, i.e., for $t = 0$, α must also become zero, since otherwise the deflection ΔV_U would become infinite. However, $\alpha = 0$ means that v_∞ and not v_2 has the direction of the vane; and that the flow is deflected, according to the two-dimensional theory, more than predicted by the one-dimensional theory.

In order to eliminate this contradiction, and thereby bridge the gap between the two-dimensional and one-dimensional approaches, the foregoing equations must be changed. Physically, it is most natural to reason that the vane in the system cannot have the same characteristics as the same vane in the corresponding position in an infinitely extended stream. This means that equation (2), which applies to the latter case, must be changed to apply to the vane in the system. The change is expressed by the "lattice-effect coefficient" K, defined by the relation

$$C_L = 2\,\pi\,K \sin\alpha \quad .. \quad .. \quad (7)$$

Then equation (5) becomes

$$2\,\pi\,K \sin\alpha = \frac{2\,\Delta V_U}{v_\infty}\,\frac{t}{l}$$

or

$$\frac{v_\infty \sin\alpha}{\Delta V_U} = \frac{t}{l}\,\frac{1}{\pi K} \quad .. \quad .. \quad (8)$$

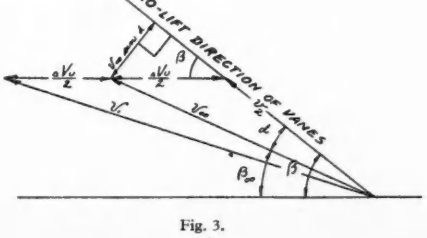


Fig. 3.

For the limiting case represented by the identity of v_2 and the direction of the vanes (Fig. 3) the relation

$$\lim_{t/l \to 0} \left(\frac{v_\infty \sin\alpha}{\frac{\Delta V_U}{2}} \right) = \sin\beta \quad .. \quad (9)$$

may be derived; and, by comparison with equation (8), it is seen that

$$\lim_{t/l \to 0} \left(\frac{t}{l}\,\frac{2}{\pi K} \right) = \sin\beta$$

or

$$\lim_{t/l \to 0} K = \frac{t}{l}\,\frac{2}{\pi \sin\beta} \quad .. \quad .. \quad (10)$$

Equations (9) and (10), when written in the forms

$$v_\infty \sin\alpha = \frac{\Delta V_U}{2} \sin\beta \quad .. \quad .. \quad (9a)$$

and

$$K = \frac{t}{l}\,\frac{2}{\pi \sin\beta} \quad .. \quad .. \quad (10a)$$

may be considered as the one-dimensional approximation for the flow conditions in systems of straight and parallel vanes. This approximation for the lattice-effect coefficient K is represented graphically by the straight lines in Fig. 4, but is obviously correct only for small values of $\frac{t}{l}$. The actual shape of the curves of K as a function of $\frac{t}{l}$ may now be estimated by the condition that these curves must approach their one-dimensional approximations for small values of $\frac{t}{l}$, and the line $K = 1$ for large values of $\frac{t}{l}$. This reasoning is confirmed by the exact K curves which are shown in Fig. 4, for $\beta = 20$ deg. and $\beta = 70$ deg., in relation to their one-dimensional approximations. A complete set of K curves, whose theoretical derivation is given by Weinig[1] is shown in Fig. 5.

Form of Vane System. It is generally known that the foregoing equations can readily be used for finding the form of the vane system from the flow or operating conditions. The method of solving this problem is essentially the following:

The vane thickness can be taken into account by the following simple approximation: A "thickness reduction ratio" C_1, which is assumed to be constant throughout the system, is derived from the relation

$$C_1 = \frac{t - \tau}{t} \quad .. \quad .. \quad (11)$$

where τ is a mean value of vane thickness, measured as shown in Fig. 1. Then, if V_a is the through-flow velocity between the vanes, and V_{a0} is the velocity before and in back of the vanes

$$V_a = \frac{V_{a0}}{C_1} \quad .. \quad .. \quad .. \quad (12)$$

where V_{a0} is calculated from the continuity relation

$$V_{a0} = \frac{Q}{(D_{0D}^2 - D_h^2)\,\frac{\pi}{4}}$$

Here D_{0D} is the outside diameter, D_h the hub diameter, and Q is the rate of through-flow in volume per unit of time.

For all subsequent considerations, however, it is possible to make the simplifying assumption

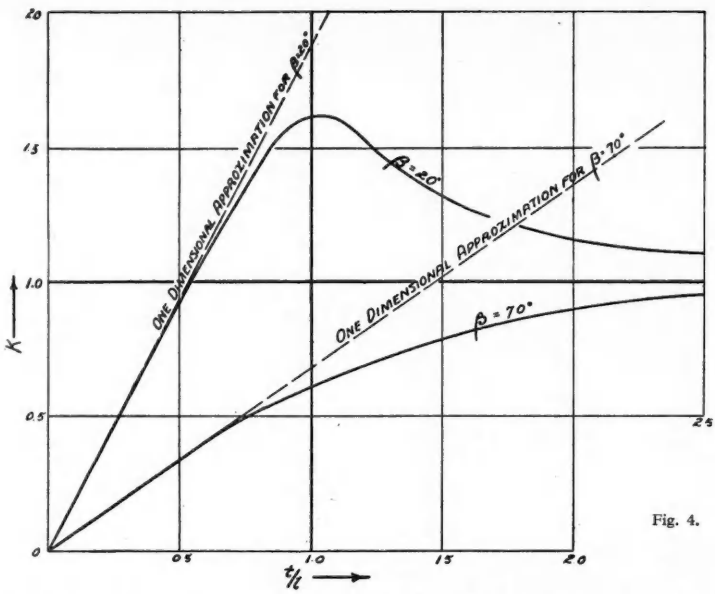


Fig. 4.

$$V_{a1} = V_{a2} = V_a = \text{const.}$$

that is, to use for the axial-velocity component the same value before, between, and after the vanes.

The relation between ΔV_U, H, and U is given by the Euler equation

$$\frac{H}{\eta_h} = \frac{\Delta V_U U}{g} \quad .. \quad .. \quad .. \quad (13)$$

where η_h is the " hydraulic efficiency " of the machine. Thus the form of the velocity diagram is determined, since U, V_a, V_1, and ΔV_U are given by the impeller inlet and operating conditions. It is now possible to design the vane shape in such a manner as to satisfy this velocity diagram.

From equation (5) C_L may be derived by assuming a value for $\frac{t}{l}$; or $\frac{t}{l}$ may be calculated by assuming a value for C_L from wind-tunnel tests.

The angle of attack α may now be determined from C_L according to equation (7). In order to determine in this equation the coefficient K (from the diagram, Fig. 5), it is first necessary to estimate β, which is slightly greater than $\beta\infty$ (known from the velocity diagram).

From the final value of α is derived the vane angle $\beta = \beta\infty + \alpha$ which determines the zero-lift direction of the vanes (see Fig. 1). The curvature of the vanes may be chosen so that the direction of the leading portion matches the direction of the relative inlet velocity, v_1.

The derivation of the flow in individual cylindrical sections which has just been described could also have been accomplished on the basis of the one-dimensional theory. Departures of the flow from the direction of the trailing edge of the vane can be expressed by a correction factor C_H which modifies the Euler equation in the form

$$H = \eta_h C_H \frac{(V_{U2}^* - V_{U1}) U}{g} \quad .. \quad (14)$$

where V_{U2}^* is defined by the fact that the corresponding relative velocity is parallel to the direction of the discharge portion of the vane (see Fig. 1). In general, this correction factor is determined empirically. It is, however, also possible to determine it on the basis of the results of the two-dimensional theory, in analogy with the method of determining K.

The first approximation of K was obtained by equating the results of the two-dimensional theory to those of the one-dimensional theory, putting the correction factor of the latter, C_H, equal to unity. This first approximation of K, however, was improved by the exact solution of the two-dimensional flow through a system of straight and parallel vanes. With these improved K values, it is then possible to determine the correction factor C_H of the one-dimensional theory, that is, by the inverse of the process by which the first approximation of K was originally obtained.

Equation (14) may be written in the form

$$\frac{H}{\eta_h} = C_H \Delta V_U^* \frac{U}{g} = \Delta V_U \frac{U}{g} \quad .. \quad (15)$$

where $\Delta V_U^* = V_{U2}^* - V_{U1}$, while ΔV_U is the corresponding actual value of the change of the peripheral fluid velocity.

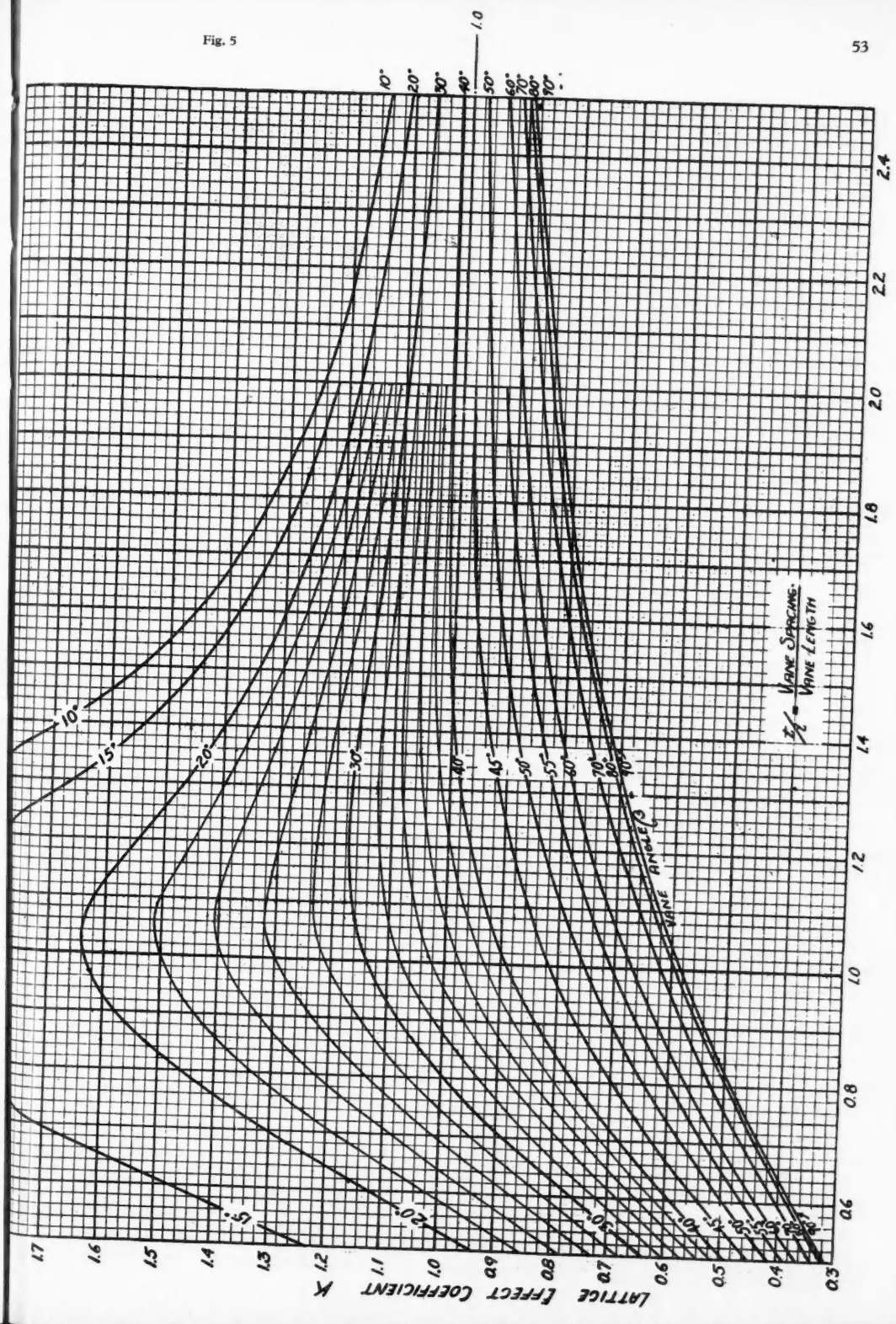
But it is seen that

$$C_H = \frac{2}{\frac{t}{l}\frac{2}{\pi K}\frac{1}{\sin\beta} + 1} \quad .. \quad .. \quad (16)$$

Since these C_H values are derived from the two-dimensional theory by using theoretical K values, it follows that they apply directly only to systems of straight and parallel vanes, because only for this case are the theoretical K values strictly applicable. It is possible, however, to use these C_H values for other vane forms, provided that the average direction of the discharge portion of the vane is chosen to be equal to the zero-lift direction, as in Figs. 1 and 2.

At this point, it is well to consider the fact that the head may vary as a function of two variables, namely, the rate of through-flow and the distance r from the centre of rotation in the runner. (This fact is demonstrated by Figs. 6 and 7).

Variations as a function of the rate of through-flow were previously discussed, while in the following


LATTICE EFFECT COEFFICIENT K
VANE ORIENTATION
s/l = VANE SPACING / VANE LENGTH
10°
15°
20°
30°
40°
45°
50°
55°
60°
70°
80°
90°

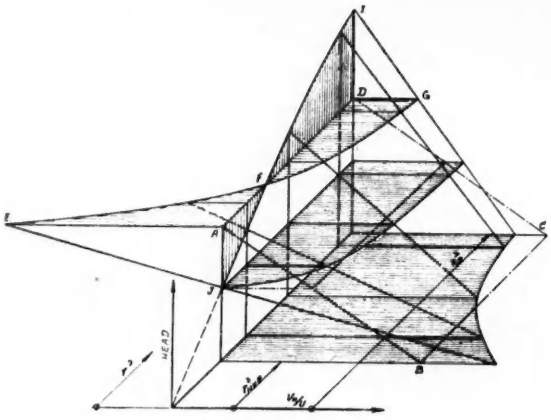


Fig. 6

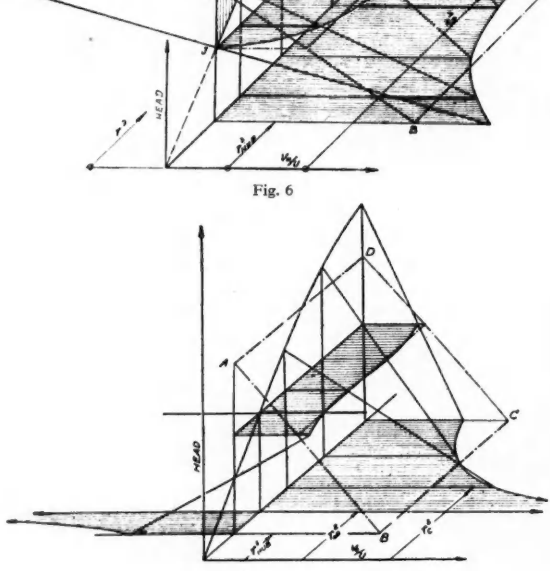


Fig. 7.

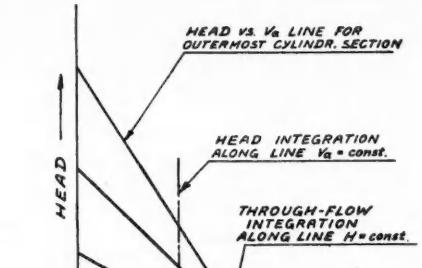

HEAD VS. Va LINE FOR OUTERMOST CYLINDR. SECTION
HEAD INTEGRATION ALONG LINE Va = const.
THROUGH-FLOW INTEGRATION ALONG LINE H = const.
HEAD VS. Va LINE FOR HUB SECTION
HEAD
LOCAL THROUGH-FLOW VELOCITY Va

Fig. 8.

sections the variations as a function of r are of major importance. "Constant head" or "variable head" therefore refers in the following discussion to the latter variation over the cross section :

In some publications, notably those by O'Brien[2] and Folsom, and by Wattendorf[3], the head of the machine is calculated as the average of different head values produced by the various cylindrical sections through the runner; only at the "design point" are these values assumed to be equal at the same through-flow velocity V_a. Away from this point, the head is averaged, by multiplying each local head value by the narrow ring cross-section to which it applies.

$$\pi\,(r_{0D}^2 - r_{hub}^2)\,H = \int_{hub}^{0D} H_a\,da = \int_{r_{hub}}^{r_{0D}} H_a\,2\,\pi\,r\,dr \quad (17)$$

The through-flow velocity is assumed to be constant over the impeller cross-section. This approach can best be represented by a vertical section through the bundle of local head *vs.* through-flow curves in Fig. 8.

The differences in pump head which are averaged by equation (17) may be quite large. For approximately constant energy distribution at the inlet side of the runner, correspondingly large head or energy differences must be assumed to exist in the stream leaving the impeller. If the capacity differs appreciably from the design conditions, these theoretical energy differences may well exceed the velocity head of the average through-flow. In this case it becomes difficult to understand how this stream can form, further away from the runner, a flow of approximately constant energy. While such head differences between the individual vane sections have been observed by means of pilot-tube measurements, the resulting head of the machine did not seem to be consistent with the results obtained according to equation (17).

A more serious difficulty arises from the question of whether the variations in pump head assumed by this theory are compatible with the requirement that the differences in static pressure over the cross section must be in equilibrium with the centrifugal forces of the rotating fluid masses. It can, however, be shown that for a flow of constant angular momentum at one side of the runner (this includes the case of zero rotation), the requirement of equilibrium of radial forces is satisfied only if the head produced along all the cylindrical stream surfaces of the runner is the same. The only exception to this rule will be the fictitious case that the fluid leaves the runner at a rotational velocity equal to the runner velocity ($V_{U2} = U$); that is, the whole mass of fluid leaving the runner rotates as a solid body at the velocity of the runner. This case, however, is not realized in axial-flow pumping machinery.

1 Univ. California Pub., Vol. 4, No. 1, 1939.
2 California Inst. Technol., Th. von Karman Anniv. Vol., 1941

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3. "The Ideal Performance of Curved-Lattice Fans," by F. L. Wattendorf, Th. von Kármán Anniversary Volume, California Institute of Technology, 1941.
4. "Die Kreiselpumpen," by C. Pfleiderer, J. Springer, Berlin, 1932.
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6. "Abriss der Strömungslehre," by L. Prandtl, F. Vieweg & Son, Braunschweig, 1935.
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TECHNICAL NEWS

Announcements in this section include News relating to British Firms, and on Equipment produced by British Manufacturers.
Available literature may be secured by addressing a request to the advertising department of "The Engineers' Digest," or by writing direct to the manufacturer and mentioning "The Engineers' Digest" as a source.

- NEW EQUIPMENT
- BOOKS AND CATALOGUES
- BUSINESS CHANGES
- PERSONAL
- NOTES

PERSONAL.

Sir Clive Baillieu, President of the Federation of British Industries, has been nominated for a second year of office. The Grand Council meeting has also decided that **Sir Guy Locock,** the retiring director, be recommended for election as a Vice-President of the Federation.

Mr. J. H. Brebner, O.B.E., has been appointed Chief Public Relations and Publicity Officer, London Passenger Transport Board.

Mr. D. W. Cooper, lately Director of Machine Tool Disposal, Ministry of Supply, has joined the Board of the Selson Machine Tool Company, Ltd.

Mr. Robert Foot, Chairman of the Mining Association, has been appointed Chairman also of the Council of the British Coal Utilisation Research Association.

Mr. T. M. Herbert has been appointed Manager of the Scientific Research Department, Watford H.Q., L.M.S. Railway Company.

Mr. H. A. Marquand, M.P., Secretary for Overseas Trade, has appointed **Mr. R. L. J. Wills** to be his Private Secretary, in succession to **Mr. C. C. I. Lambert.**

Sir Frank Nixon has been elected a Director of John Brown & Co. Ltd. He will become chairman of a special export company which is being formed to promote the export trade of John Brown & Co., Ltd., Thomas Firth & John Brown Ltd., and their subsidiary and associated companies.

The Central Electricity Board has appointed **Mr. G. R. Peterson,** B.A., A.M.I.E.E., Chief Assistant Operation Engineer, Head Office, to be Operation Engineer for the North-West England and North Wales grid scheme area.

Mr. F. S. Whalley, M.C. (Vice-Chairman and Managing Director of the Vulcan Foundry Limited, and President of the Locomotive Manufacturers' Association), has been nominated President of the Institution of Locomotive Engineers for 1946-47.

NEW BOOKS AND LITERATURE.

"Electron Optics and the Electron Microscope," by V. K. Zworykin, E.E., Ph.D.; G. A. Morton, Ph.D.; E. G. Ramberg, Ph.D.; J. Hillier, Ph.D.; A. W. Vance, E.E. Published by John Wiley & Sons Inc., New York; Chapman & Hall Ltd., London. Price ten dollars.

A FORMIDABLE team of experts of the Radio Corporation of America have combined to produce this outstanding work. The book has a twofold purpose, first to aid the electron microscopist in understanding and utilizing his instrument to the best advantage, and second, to give the electron optical designer essential information for the improvement of instruments. Part I. describes the various types of microscopes and is a practical guide to their operation, and contains a non-mathematical discussion of electron optical theories on which the electron microscope is based. Part II. supplements Part I. by giving a survey of theoretical electron optics in addition to employing mathematics in keeping with the development of the subject. Some of the valuable data in the book covers principles of electron optics, design and construction of components, measurements and calculations, tracing of electron rays, properties of lenses, noise problems and essential tables. It is a book that none interested in the subject can afford to be without.

Handbook for Electric Welders. Published by Murex Welding Processes Ltd., Waltham Cross, Herts. Price 5s. net.

THIS well known work has been thoroughly revised and contains a store of new information on up-to-date practice and developments in the art of welding. Much of the purely elementary matter on methods of welding, given in previous issues, has been omitted and the book deals with the subject on broader lines. The handbook is thus a valuable guide to those wishing to perfect their knowledge of the application of welding to special materials, the physical properties, strength and testing of welded joints and electrode data.

Elastomeric Engineering. Published by Andre Rubber Co. Ltd., Kingston-by-Pass, Surbiton, Surrey. Price 21s., post free.

THIS useful book provides a guide to the application of rubber-bonded-to-metal elements in the whole field of engineering. In addition to the drawings, illustrations and text describing actual applications of rubber-bonded-to-metal elements, some detailed description is given of the processes of manufacture and the plant and tools involved. "Elastomeric Engineering" in its new form is a complete book of reference for Executive Engineers, Designers and leading Draughtsmen, and they may obtain a copy from the publishers, without charge, if their request is made on business notepaper and states their position. A limited number of copies are available for private purchasers at the price stated.

THE MANUFACTURE AND PRODUCTION OF ALUMINIUM-ALLOY FORGINGS AND STAMPINGS.

To those practised in working with steel and copper-base alloys, the forging of aluminium alloys is likely to present some difficulty. The aluminium alloys have lower melting points and their hot working range is below "red heat," so that the technique demanded in the production of forgings is to those accustomed to the older arts, a new one.

At the present time heavy tonnages of aluminium alloys are being produced without difficulty, in hundreds of forges through-

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out the world, and a brochure, prepared and published by the Technical Committee of the Wrought Light Alloys Association, whilst supplying useful information to those familiar with light alloy forgings, will be found to be invaluable by Forgers approaching the problems of forging aluminium alloys for the first time, since it presents concisely but in detail all the facts relevant to the manufacture of good quality light alloy forgings.

In this country forgings are made primarily from extruded bar or cast blanks. These have markedly different characteristics, which involve different techniques of handling during forging, and the authors rightly deal in detail with the production of forging stock by both methods. The preparation of blanks for forging is then discussed both in terms of the machining requirements and preheating for forging; under the latter heading, the types of furnace most suitable for the purpose are described. The importance of accurate furnace control is emphasised, as is the importance of the time-factor in the heating of the stock to forging temperature. A rough method of ensuring that the stock is held long enough in the furnace is to maintain the blanks at the set period for approximately one hour per inch of their thickness.

The plant required for the manufacture of forgings is considered and the essentials of the modern forge-drop hammers, friction presses, pneumatic hammers, clipping tools, swaging or fuller tools and die blocks. The supreme importance of die design is stressed, and a complete layout of the whole process of the manufacture of a forging is recommended. This should include all operations from the machining of the die to the final stamping of the dummies; while such features as size, shape, direction of grain flow, shrinkage, and the position of the die in the drop hammer, must all be predetermined.

The brochure is lavishly illustrated with photographs, line drawings and graphs; and much information is presented in tabular form. Copies may be obtained from the Aluminium Development Association, 63, Temple Road, Birmingham.

Bronzecraft. Weldcraft Ltd., an associate company of Hancock & Co. (Engineers) Ltd., Progress Way, Croydon, have issued a new leaflet describing the "Bronzecraft" series of welding rods These rods have been specially developed for non-fusion welding at low temperatures and enable joints of high strength to be made without the necessity of high temperatures, thus eliminating thermal disturbance inherent in normal welding. The rods are made in three types, No. 1 is a Silicon bronze alloy for use on brass, bronze and copper; No. 2 a Manganese bronze alloy for cast iron and mild steel; and No. 3 a Nickel bronze alloy for use on mild and alloy steels and stainless steels.

NEW EQUIPMENT.

THE DOWTY LIQUID SPRING.

THE technicians of Dowty Equipment Ltd., have perfected a liquid spring which operates at pressures up to 100,000 pounds per square inch.

The device has already proved to be a perfect method of suspension for aircraft undercarriages, and for other purposes, i.e., heavy transport, drop hammers, oil circuit-breakers, and weaving looms. When tested on motor vehicles an amazing improvement in suspension and road holding is effected.

The Dowty Liquid Spring consists of a pressure-sealed cylinder filled with oil and a piston which has a valve mechanism. When the piston moves into the cylinder the oil is compressed and transferred from one side of the piston to the other through the valve which opens during compression and closes during recoil. The speed of compression and recovery can be controlled by varying the port apertures in the valve.

No external pressure system is necessary initially but when the piston moves into the cylinder, the piston rod goes with it and because of the differential volume of material on each side of the piston-head the oil is compressed. With light mineral oil, a compression of no less than 20 per cent of the original volume is obtained with a pressure of 60,000 pounds per square inch.

The liquid spring has been made possible by the development of the special gland which permits smooth action under enormous pressures. The gland is in three main parts. A steel pressure plate, carrying four dowel pins, butts against the cylinder step and the dowel pins pass through a resilient gland ring into holes in a backing plate. A foraminated disc is placed between the gland and pressure plate and so prevents a pressure lock.

Compared with a steel coil spring, the liquid spring shows an immense saving in size, material and weight, for instance, a steel spring to take a load of 20 tons for 4 inches deflection has a diameter of 10⅝ inches and weighs 125 lbs., whereas a liquid spring for the same load weighs 21 lbs., and is only 3⅝ inches diameter.

The strength and reliability of the liquid spring has been demonstrated by a set which, when fitted to a Halifax aircraft, survived two crash landings, and was subjected to 500 landings without attention of any kind.

MECHANICAL AND ELECTRICAL ENGINEERS AND METALLURGISTS

who are interested in translating and abstracting technical articles from foreign engineering journals and proceedings of engineering societies, are requested to write to the Editor, THE ENGINEERS' DIGEST, 120, Wigmore Street, London, W.1. We wish to secure the services of specialists on various engineering subjects, who have sound theoretical and practical knowledge as well as linguistic abilities. We offer regular part-time or occasional work and good remuneration.

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REPORT FROM SWITZERLAND.

SWITZERLAND has no oil, no coal, no raw materials, little iron. Indeed, it has only water-power and brain-power. Recent statistics[1] give astonishing figures which reveal ingenuity. While the United States grants annually 330 patents per million of population, the corresponding figure in Switzerland is 930. The same source gives the wealth per capita in the U.S.A. as $2098, and in Switzerland $3126. These figures should not be overestimated in their importance, yet they indicate the conditions typical to the Swiss, namely, of a small nation which, in the way it sets out to solve its problems, offers many a lesson to the great industrial nations. The special requirements arising out of the smallness of the country and the way in which these are satisfied, are worthy of study, not only due to their inherent value to the Western World, but as an indication of the importance of Switzerland for American export as well as a competitor on foreign markets.

The Swiss were able to devote the greatest part of their efforts during the war years to peaceful production, and are definitely ahead of their competitors in many questions of technique, particularly in welding.[2] This technique enabled them to build light-weight railway coaches in steel, resulting in great fuel saving in operation. (They have also put to service a riveted light-alloy type of coach which is very promising).

Many of their achievements during the last few years are recorded in THE ENGINEERS' DIGEST. In the past three years alone we have published well over fifty Swiss papers which we thought to be representative of their industrial activities. We believe the Swiss have been using first braking or reverse pitch propellers now finding common acceptance.[3] Noteworthy further achievements are their improvements in the efficiencies of steam turbines,[4] and pioneer work on gas turbines[5] in the many varieties of this new prime mover, including the marine variety. No small affair for a country without access to the sea.

In order to give a further example that is characteristic for the outlook of the Swiss engineer, we shall quote a few passages from a report that becomes available now, although having been published in 1943.[6] One of the papers in this report is written by Prof. Dr. J. Ackeret, and describes the Institute for Aerodynamics at the Federal Technical College in Zurich (ETH). It deals mostly with the wind tunnels of the Institute, and Fig. 1 shows one of the tunnels adopted and the reduction in size obtaining over a comparable type.

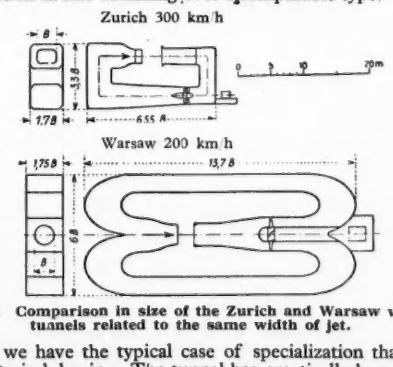

Fig. 1. **Comparison in size of the Zurich and Warsaw wind tunnels related to the same width of jet.**

Here we have the typical case of specialization that it pays to indulge in. The tunnel has practically been repeated in Holland,[7] and was equally satisfactory. Much that is contained in the present report on the Zurich supersonic wind tunnel has been published in THE ENGINEERS' DIGEST.[8] As a later development, the supersonic plant has been extended so that it can be switched over to testing of an experimental aerodynamic turbine shown in Fig. 2. (See p. 58). (The plant can be used alternately as in Fig. 2, or as in Fig. 11 on page 267 of Reference 8).

This experimental turbine installation could only be financed by using also the fonds of Prof. H. Quiby, who is the successor in the late Prof. Stodola's chair. The reasons for this co-operation are explained by Prof. Ackeret: "The designer of steam and gas turbines is greatly interested in the development of aerodynamics as the methods of the latter science enable the investigation of losses and thereby contribute to the improvement of efficiencies. While these improvements are certainly desirable in steam turbines, they cannot be revolutionary. With the gas turbines, however, these improvements are of the utmost importance. Without exaggeration it can be said that in gas turbines the problems are as much of an aerodynamic nature as they are material problems." There are signs that research into the latter aspect is not neglected either. Brown Boveri had patented a blade, the manufacture of which is made possible by a technique of powder metallurgy. The material is so distributed that at the blade root there is 100 per cent metal, and at the tip 100 per cent ceramic. Not much is know about the permanent value of these developments.

With the experimental turbine shown in Fig. 2 the speed is kept constant, and the Reynolds' number can be changed by variation of pressure. This expedient enables investigation into the effect of Reynolds' number independently of compressibility effects. Similarly, for constant Reynolds' number the Mach number can be varied. As the turbine cannot always take the full mass flow of the compressor, a by-pass pipe is provided which leads to excess cooled air via an ejector back into the circuit; the ejector improves the pressure ratio. Power is measured electrically to obtain full braking torque at lowest speeds for the investigation of turbines for traction purposes, such as locomotives. The braking dynamo can be fed as a motor, to enable the investigation of astern operation of ship turbines. Special flow measurements can be made, and the flow is made visible.

The buildings of the Federal College are heated by Heat Pumps,[9] another Swiss achievement. About two-thirds of the heat requirements are covered by the "low" heat of the nearby river water, the rest comes from electricity supplied to the driving motors. We have mentioned the specific factor arising out of the smallness of Switzerland. In the case of the aforementioned research equipment, to give one example, the special problem was to serve several purposes with one plant. Therefore, the aerodynamic laboratory of Zurich is built so as to enable them to carry out within one plant alternate investigations into aircraft design problems, tests for turbine blade design, wind pressure tests on high structure models, and other related problems.

Our readers will find some contributions in this as well as in the following issues of our journal that may confirm and deepen the impression reflected by the foregoing discussions.

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[2] E.D. 1943, p. 70. 1944, p. 355.
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[6] Mittellungen aus dem Institut für Aerodynamik, Eidgenossische Technische Hochschule, Zurich, 1943. Verlag A.G. Gebr. Leeman & Co.
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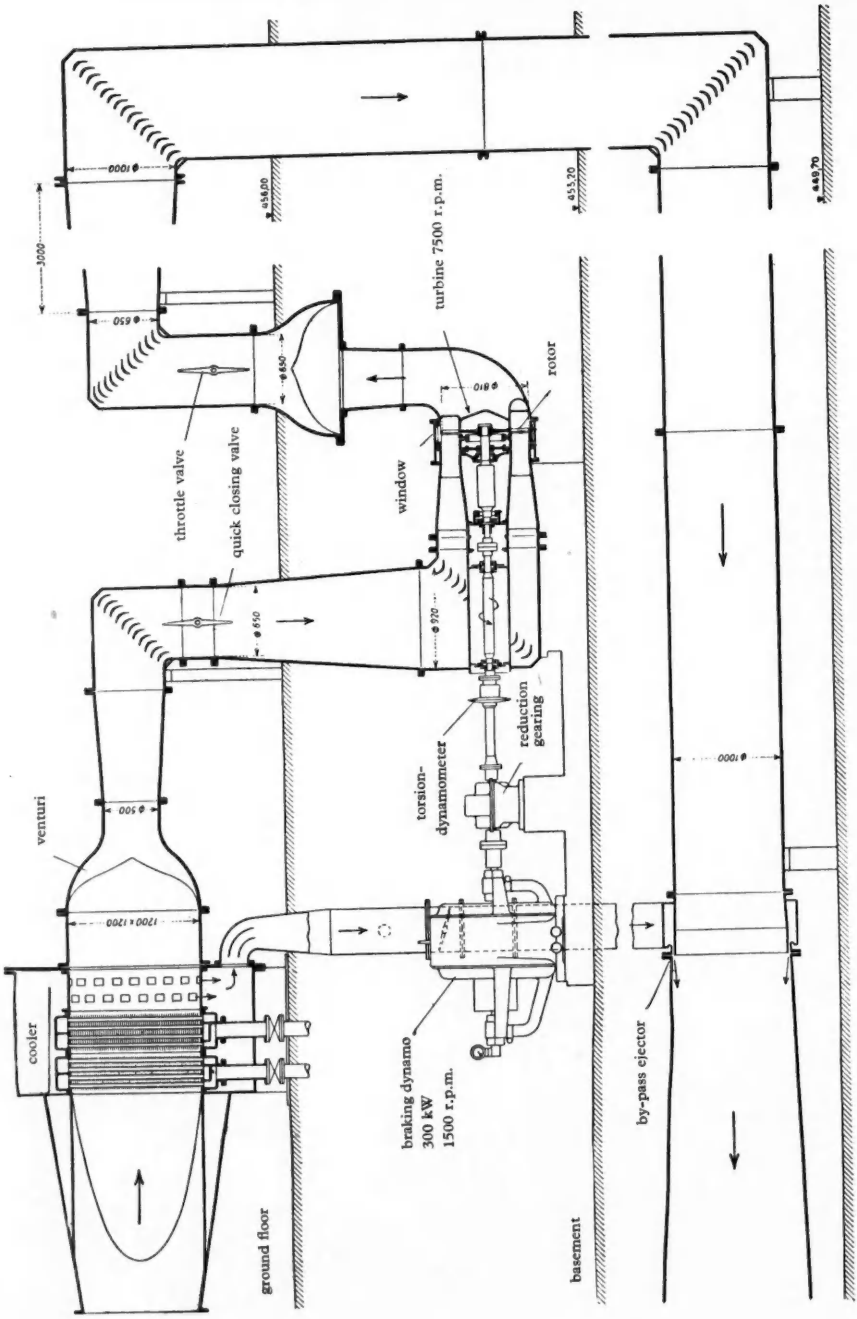


Fig. 2. **Layout of the 300 kw. experimental aerodynamic turbine in the circuit of the supersonic tunnel.**

THE MODULUS OF ELASTICITY OF WOOD AND ITS VARIATION WITH THE ANGLE BETWEEN THE DIRECTIONS OF FORCE AND GRAIN.

By F. STUSSI. (From *Schweizerische Bauzeitung*, Vol. 126, No. 22, December 1st, 1945, pp. 247-248).

THE mechanical properties of wood vary with the angle γ between the grain and the force applied. The variations of the strengths σ and the permissible elastic deformations as a function of this angle have been investigated by various scientific workers, including F. Kollmann, who developed the following empirical formula for the strength σ_γ:

$$\sigma_\gamma = \frac{1}{\frac{\cos^n\gamma}{\sigma_\parallel} + \frac{\sin^n\gamma}{\sigma_\perp}} = \frac{\sigma_\parallel \ \sigma_\perp}{\sigma_\perp \cos^n\gamma + \sigma_\parallel \sin^n\gamma} \quad \ldots (1)$$

where $\sigma_\parallel$ is the strength parallel, and $\sigma_\perp$ the strength perpendicular, to the grain, and n an exponent varying between 1·5 and 2 for tensile stresses and between 2·5 to 3 for compression. Although this formula is one of the best yet developed, it does not always give sufficiently accurate results and its application involves calculations which may, on many occasions, be felt to be somewhat cumbersome for the designer.

It can, however, be transformed by putting:

$$\sigma_\gamma = \varphi_1 \ \sigma_\parallel \cos^2\gamma + \varphi_2 \ \sigma_\perp \sin^2\gamma, \text{ and}$$

$$\varphi_1 = \frac{1}{\sqrt{1 + C_1 \sin^2\gamma}}, \quad \varphi_2 = \frac{1}{\sqrt{1 + C_2 \cos^2\gamma}}$$

into:

$$\sigma_\gamma = \sigma_\parallel \frac{\cos^2\gamma}{\sqrt{1 + C_1 \sin^2\gamma}} + \sigma_\perp \frac{\sin^2\gamma}{\sqrt{1 + C_2 \cos^2\gamma}} \quad (2)$$

where C_1 and C_2 are constants for any given type of wood and must be determined experimentally. This formula yields more accurate results than formula (1) as will be seen from Fig. 2. Fig. 3 shows calculated and measured values for Gotthard pine.

The main value of equation (2) lies in the fact that it can be used for calculating permissible stresses $\sigma_{\gamma\,\text{perm}}$ if the permissible values for $\sigma_\parallel$ and $\sigma_\perp$ are stipulated, e.g., by a specification. Fig. 4 shows the ratio $\sigma_{\gamma\,\text{perm}}$: $\sigma_{\parallel\,\text{perm}}$ for compression, calculated from equation (2) with $\sigma_{\perp\,\text{perm}} = 0{\cdot}20\sigma_{\parallel\,\text{perm}}$, $C_1 = 7{\cdot}0$ and $C_2 = 1{\cdot}5$.

Another advantage of formula (2) is that it can be applied not only for calculating the stresses σ_γ but also for calculating with reasonable accuracy the variations of the modulus of elasticity as a function of the angle γ.

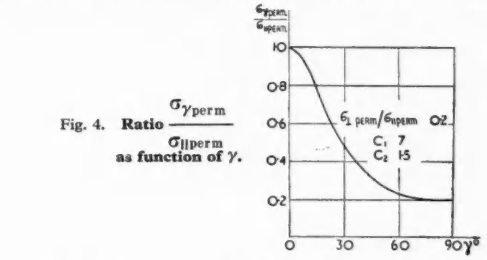


Fig. 4. **Ratio $\frac{\sigma_{\gamma\,\text{perm}}}{\sigma_{\parallel\,\text{perm}}}$ as function of γ.**

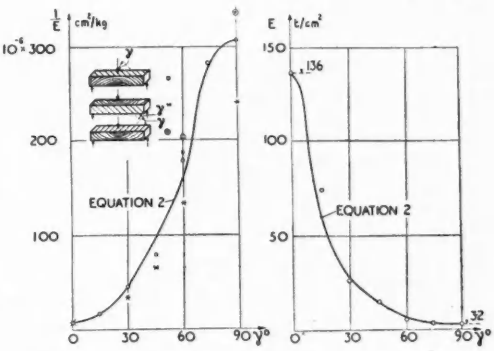


Fig. 5. **Elongation factor $\alpha = \frac{1}{E}$ and moduli of elasticity E as functions of γ.**

Fig. 5 shows measured values for the elongation factor $\alpha = \frac{1}{E}$ in bending (Gotthard pine) and the corresponding moduli of elasticity E, as well as the curves for α and E as calculated from equation (2) with $C_1 = 16$, $C_2 = 3$ for α, and $C_1 = 50$, $C_2 = 10$ for E.

Figs. 2 and 3 may suffice to prove the usefulness and applicability of formula (2).

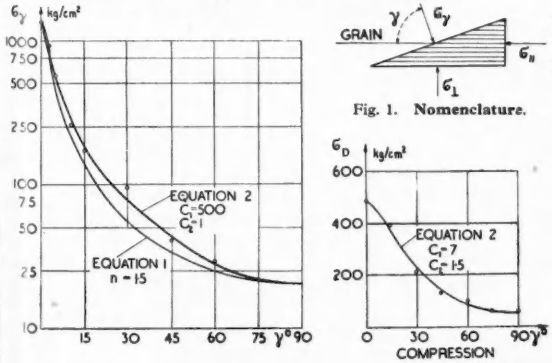


Fig. 1. **Nomenclature.**

Fig. 2. **Tensile strength of birch plywood.**

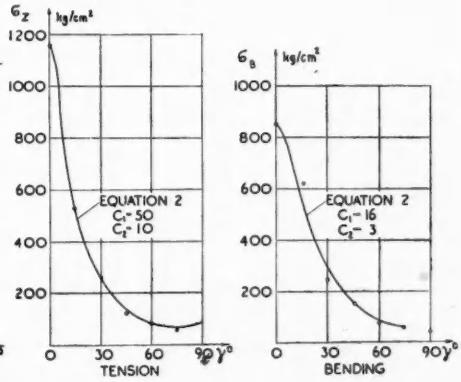


Fig. 3. **Strength of Gotthard pine.**

SPOT WELDING OF LIGHT METALS IN AIRCRAFT MANUFACTURE.

By W. HEIZ. (From *Schweizer Archiv.*, Vol. 10, No. 8, pp. 241–252.)

SPOT welding as a method of jointing can only be compared with riveting. Figs. 1 and 2 illustrate some important aspects for comparison; other aspects may reverse the conditions in special cases and more tests and experience in practice may be needed before definite conclusions can be formed whether spot welding, in the manufacture of aircraft, should replace riveting to a larger extent than is usual at present.

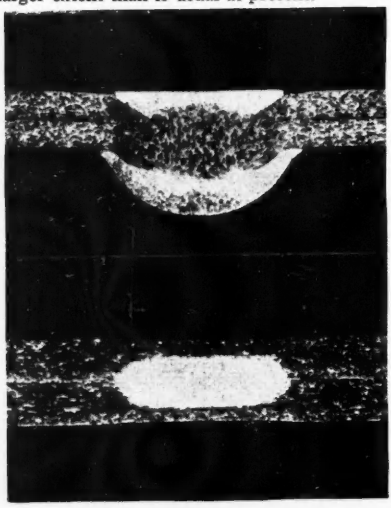


Fig. 1. **Comparison of a riveted and a spot welded joint.**
Top: Mushroom head rivet.
Bottom: Spot weld.
Material: Al–Cu–Mg.

A riveted joint can be replaced by a spot weld of equal tensile strength whilst a saving of material takes place but, there are limitations to the application of spot welding in aircraft manufacture, viz. :—

(1) Parts exposed to heavy and changing loads are usually riveted.
(2) Parts on which safe and efficient welding cannot be guaranteed because of inaccessibility for welding or other reason and which must therefore be riveted.
(3) Parts that are to be interchanged may need to be riveted.
(4) Riveting by means of automatic machinery will be preferred if it is more economical.
(5) Spot welding will be adopted only if the quantity warrants the purchase of the tools and electrodes, or if rivet heads are not permissible for aerodynamic reasons.
(6) Riveting must be used if it is impossible to prepare the parts for welding, e.g., if they are coated with anti-corrosion paint, etc.

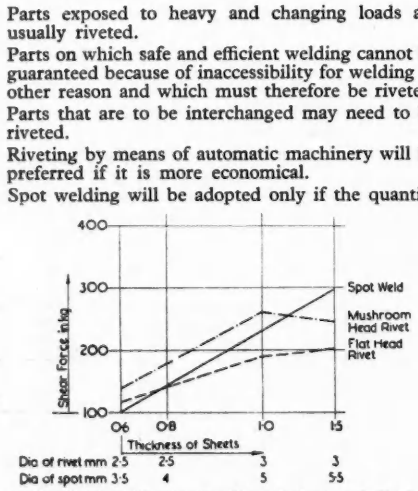


Fig. 2. **Tensile strength of spot welds and rivets on individual spot welds and rivets respectively.**

SPOT DIAMETER OR SPOT IMPRESSION.

The impression of the electrode on one or both surfaces of the work is the only characteristic of spot welding that can be seen and measured without difficulty (see Fig. 3). Its diameter increases in proportion to

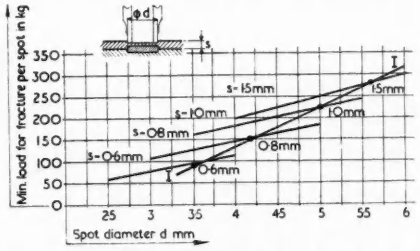


Fig. 3. **Influence of the diameter of spot welds on the tensile strength. Best results.**
Sciaky machine.
Material: Al–Cu–Mg.

the thickness of the sheets. Consequently the largest impressions may be considered best. From a certain size upwards, however, cracks take place on the surface and heat damaged surfaces appear which are more or less exposed to corrosion according to the material of the sheets. The size of impressions of the greatest strength has been determined by tests as shown in fig. 3 for all thicknesses of sheets. They are represented by the line I—I with about the following limits :—

0·6 mm.	sheet approximately	3·5 mm.	spot diameter
0·8 mm.	,, ,,	4–4·5 mm.	,, ,,
1·0 mm.	,, ,,	5 mm.	,, ,,
1·5 mm.	,, ,,	5·5–6 mm.	,, ,,

Circular impressions and straight spot surfaces can be obtained only with special electrodes and tapered electrodes with a flat pad are probably the best.

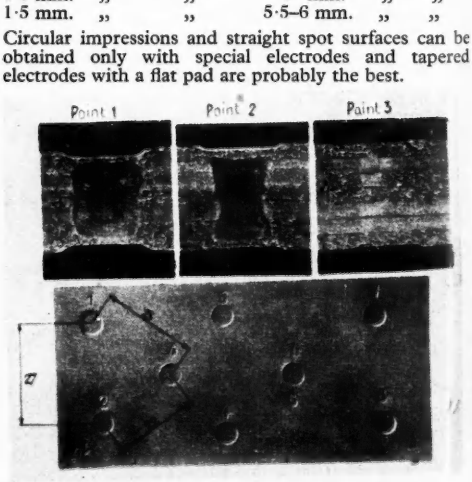


Fig. 4. **Shunt effect during spot welding.**
Material: Al–Cu–Mg. 7 × 1 mm.
Machine: Sciaky 40 kVA.

DISTANCE OF WELDING SPOTS FROM EACH OTHER.

Although there is practically no lower limit to the distance between welding spots, a part of the welding current passes through existing spots if these are placed too near to each other. The waste of current is the greater the closer the welding spots are, and weak points beyond control will result. Fig. 4 shows the first welded spot of normal dimensions, the second spot is noticeably weaker, whilst the loss of current was too great to allow any welding to take place on spot 3.

Fig. 5 shows the effect of the spot distance on the spot strength and on the seam strength for four thicknesses of sheet. The spot strength increases with the

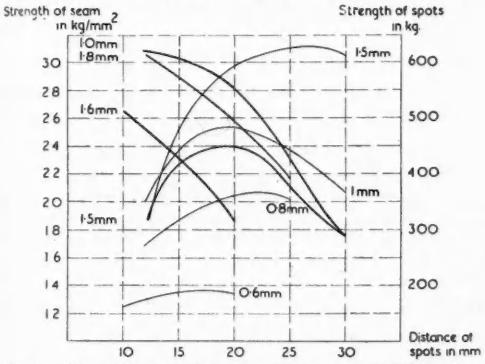


Fig. 5. **Strength of spots and seams in spot welding with "Avional" plotted against the distances of the spots.**

distance and attains a maximum corresponding to the thickness of the sheets. This is obviously due to the shunt effect. After a certain distance is reached the strength decreases again. Tensile tests show a cross deformation of the surface of the sheets just before fracture. The additional bend results in decreasing spot strength and this decrease is the larger the greater the distance between the spots.

The seam strength, however, is the greater the nearer the spots are to each other; the maximum would be obtained at the smallest possible distance, i.e., at the "seam" with the distance nil. The deviation of the curve of the 1·5 mm. sheet, Fig. 5, is due to the fact that the capacity of the testing machine was insufficient for this size.

Considerations of strength require small distances between welding spots, whilst workshop practice and economy ask for large distances. The final decision

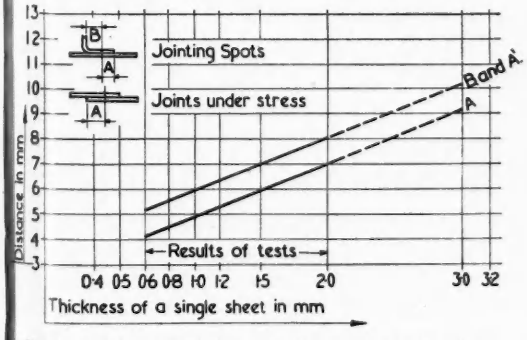


Fig. 6. **Distance of welding spots from edges and sections plotted against the thickness of sheets.**
Minimum and maximum distances according to information from foreign aircraft factories.

depends always on purpose and stress required of the weld, but as a general guide it can be stated that distances of spots between 12 mm. and 25 mm. should be used, according to the thickness of the sheets.

DISTANCE OF WELDING SPOTS FROM CORNERS AND EDGES.

These distances depend on the spot diameter, the shape of the electrode, the thickness of the sheets and the form of the joints. Fig. 6 shows the minimum distances from the edge to the centre of the welding spot when using flat electrodes in relation to the thickness of the sheets. Distances "A" should be applied to joints under low stresses, e.g., welding of supporting and stiffening sections on the sheets. The distance at which the sheets do not fracture has been fixed as a minimum. The distance "A" for joints under stress is that at which fracture results only from shear and tensile stress in consequence of a static tensile test. Distance "B" is slightly larger than distance "A" from the edge because of the insertion of some insulating material, recommended to prevent shunt currents with certainty.

EXAMINATION OF WELDING SPOTS.

The external impression does not always allow correct conclusions to be made as to size and structure of the spot weld. This is only possible by destroying the

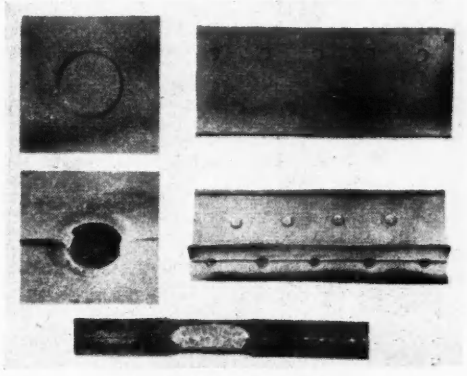


Fig. 7. **Test of spot weld.**
Material: Al-Cu-Mg. (Avional.)
Spots satisfactory.

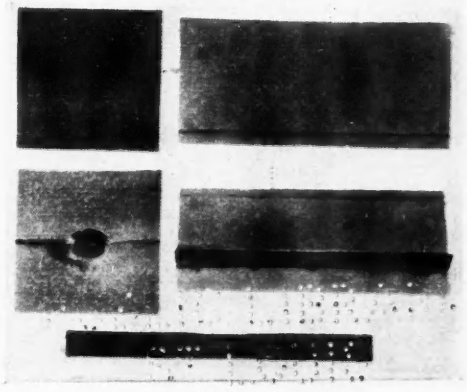


Fig. 8. **Test of spot weld.**
Material: Al-Cu-Mg. (Avional.)
Spots weak.

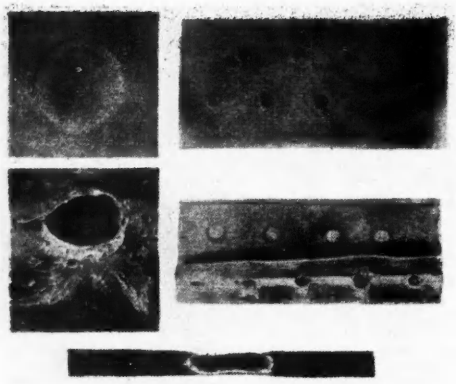
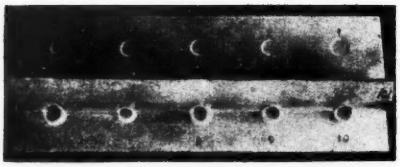


Fig. 9. **Test of spot weld.**
Material: Al–Cu–Mg. (Avional).
Spot excessive.

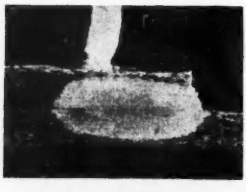
specimen by means of either separating the joint—tearing test—or cutting the specimen in two—grinding test. Figs. 7 to 9 show typical examples of these tests.

Spot welding is done in accordance with instructions based on tests which have been carried out in the laboratory. These instructions are indispensable and must be adjusted to suit the prevailing conditions in the workshops.

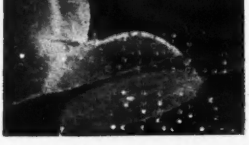
For visual inspection the two sheets have to be torn from each other (Fig. 10). A satisfactory spot weld should not tear across the sheet level in this test, but one of the sheets should peel off freely. The sizes of the actual welding spot and of the impression on the surface can then be measured and compared. It has been found that the diameter of the actual welding spot must be not less than 90 per cent of the diameter of the impression in order to guarantee a satisfactory joint.



Spot weld AL–Cu–Mg 1·5 mm.; bent open specimen: tearing test



Cross section through torn open spot weld; magnification 10 ×



Cross section and view of torn open spot.

Fig. 10. **Test of a spot weld by means of tearing test and macro grinding test.**
Material: Avional.

CRACKS AND PORES ON THE WELDING SPOT.

Cracks and pores usually appear, after the welding process has been finished, as a result of high currents, short welding times and low electrode pressure. They are dependent on certain physical qualities of the material such as heat conductivity, tensile strength, and the duration of solidification. Although non-homogeneous spot welds do not indicate conclusively a lack of strength, it is advisable to insist on crack free spot welds in the manufacture of aircraft, as all conditions exist to weld comparatively thin sheets of up to 1·5 mm. thickness without cracks. It is difficult to recognize the number and size of cracks and pores. The grinding test, the only test known at present, is unreliable as it shows the defects in one plane only.

Whilst it is well known that cracks may lead to premature fatigue fractures, no information can be given with regard to such results originating from pores. These appear in various sizes and numbers in the actual structure of the weld, particularly on light metal alloys which can be hardened. Fig. 11 shows spot welds

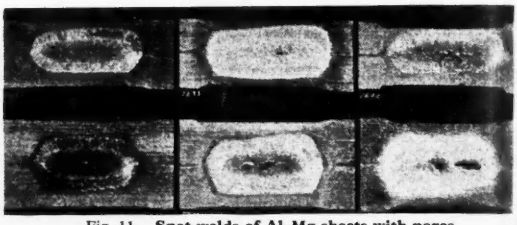


Fig. 11. **Spot welds of Al-Mg sheets with pores.**
Top: 2 × 1 mm.; below: 2 × 1.5 mm. sheets.

on Al–Mg–alloys with different agglomerations of pores. The welds on the left can be considered satisfactory, those in the centre are doubtful, and those on the right are rejects. For the time being it must be left to the workshop experts what decision to make in special cases when pores appear in spot welds.

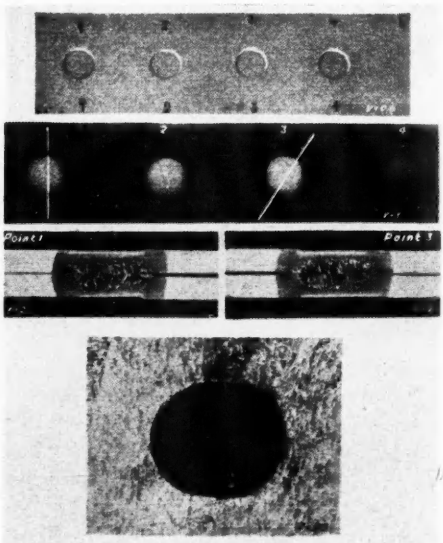


Fig. 12. **X-ray test and grinding specimen of spot welding on steel sheets 2 × 4 mm.**
Satisfactory welds.
(*a*) Photograph of weld.
(*b*) X-ray photograph.
(*c*) and (*d*) Macro grinding specimen.

X-RAY TESTS.

In contrast to other methods, the X-ray test allows examination without destruction of the weld. The spot welds for this examination were produced with an alternating current machine, the current and the electrode pressure were adjustable, and the tests were carried out on steel sheets in which defects can be demonstrated more easily than in light metals. Fig. 12 shows a faultless set of spot welds. On top, Fig. 12a, recognized by the impressions, is an ordinary photograph. Fig. 12b, the X-ray photograph, shows the spot welds as light-coloured circles. Fig. 12c is an enlarged cross-section or macro grinding specimen of the first and third welding spot. The small white spot on the X-ray photograph could be diagnosed only with difficulty in the grinding specimen. It was a non-metallic ball-shaped insertion of about 0·5 mm. diameter, and is shown greatly enlarged on the bottom photograph of a pickled grinding specimen (fig. 12d). This example demonstrates that the X-ray photograph shows minute and even unimportant defects.

Pores and cracks are easily recognizable on X-ray photographs (fig. 13). Pores appear as light spots and

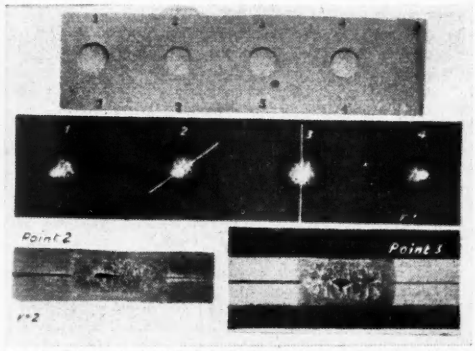


Fig. 13. **X-ray test and grinding specimen of spot welding on steel sheets 2 x 4 mm.**
Welds with cracks and pores.
Top: photograph of weld.
Centre: X-ray photograph.
Bottom: macro grinding specimen.

differ distinctly from net-shaped cracks. Grinding specimens of spots 2 and 3 coincide perfectly with the X-ray photograph. Cracks are not easily recognized on pickled grinding specimen because they follow the crystalline structure of the welding spot. They are traced easier on non-pickled specimens.

Drops of metal scattered around the welding spots and between the sheets, as a consequence of excessive welding capacity, can also be recognized on the X-ray photograph. They are not dangerous by themselves, but often coincide with blisters in the welding spot. If they are not localized to the core, but extend to the periphery of the spot, the weld may be definitely weakened.

The use of X-rays for testing spot welds has only just been started. Considering that pores and cracks are seen better on the original films than on the reproduced photographs, defects can be traced without great difficulty and with sufficient accuracy. The X-ray test has also the great advantage, in comparison with the grinding test, of showing the entire spot weld in its proper plane, parallel to the sheets. For general use in workshop practice a small X-ray apparatus should be developed which can be handled easily.

"SCIAKY" SPOT TEST.

A system of direct control during the welding process has been developed by Sciaky in Paris.

The Sciaky spot welding machine delivers the electric energy necessary for obtaining a spot weld in one impulse (fig. 15). Size and structure of the spot weld is influenced mainly by the current, i.e., in this case the maximum point in fig. 15. To control this current therefore means controlling the spot weld.

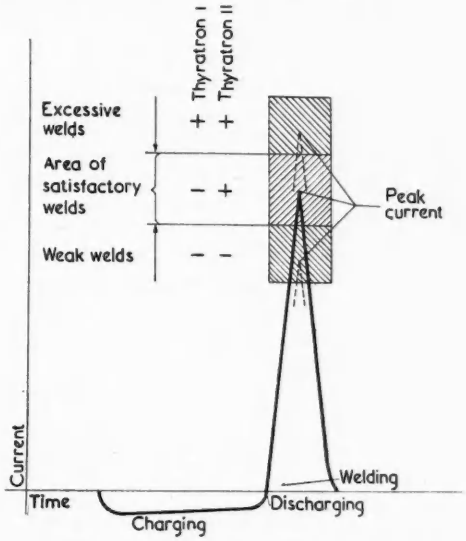


Fig. 15. **Principle of spot weld control, system Sciaky.** Thyratron I and II.

By previous tests the maximum and minimum current has been fixed for obtaining a satisfactory spot weld, thus eliminating insufficient or excessive impulses which tend to weaken the weld. The best method of measuring the maximum is to use the welding as a shunt and to measure the voltage drop between the electrodes.

These short leaks of voltage are measured and registered by means of lattice controlled valves, known as the "Thyratron," which allows the current to pass only when the lattice potential is sufficient. It is possible to control the current necessary for the spot weld in question by two such "Thyratrons." The lattice voltages of the valves are adjusted so that one of them passes the current at maximum voltage within admissible limits, whereas the other valve blocks the current (+ — fig. 15). In case of the voltage exceeding the limit both valves pass the current (+ + fig. 15). In case of the voltage reaching the lower limit, meaning insufficient current, neither of the valves pass the current (— — fig. 15).

By means of an electrical control apparatus the spots are registered according to their qualities by a counter with three scales. With good spot welds a white lamp is switched on; a green lamp in case of weak spots; and excessive welds light a red lamp. An acoustic signal is sounded in case of either excessive or weak welding and the machine is automatically stopped.

Obviously, these controls become effective only after the weld has been completed; their educational value, however, for increasing the alertness of the welder is important. The increased expenditure of time and labour connected with the introduction of the Sciaky machine with its control apparatus is negligible compared with the advantage of improved quality of the welds.

LA MONT BOILERS IN SWEDEN.

By T. WYKMAN. (From *Teknisk Tidskrift*, Vol. 75, 1945; pp. 663–672.)

OWING to the small space requirements of the heating surfaces of La Mont boilers, tnis boiler type can easily be built for high efficiency operation. Normal boilers of this kind equipped with air preheater usually have efficiencies up to 90 per cent, while for large units efficiencies as high as 92 per cent are on record. Note should be taken that these figures represent actual operating efficiencies, and are not the results of carefully prepared tests.

The single pass design of a La Mont unit installed at the plant of a Swedish steel works is illustrated in Fig. 1. This boiler is equipped for the combined firing of blast furnace gas and pulverised coal. The firing of pulverised coal is, however, only resorted to if the available blast furnace gas supply falls below requirements. The additional furnace shown in the lower right-hand side of the illustration constitutes an ante-furnace for the firing of wood shavings in the case of coal shortage. This additional furnace is also completely water-cooled by means of closely-spaced water tubes as is the main furnace. It is equipped with a slanting grate, the grate bars being cooled by water tubes, which at the same time support the grate bars. Grates of this design have proven their value on many occasions. In fact, cost of maintenance of the water-cooled grate bars is only a fraction of that of ordinary grate bars.

The topmost part of the boiler contains both an economiser and an air preheater, the two being arranged for the parallel flow of the gases. This makes it possible to obtain maximum economy in spite of the different flue gas flows obtaining with blast furnace gas and pulverised coal firing respectively. It has often been stated that the firing of blast furnace gas under boilers leads to operational trouble owing to the accumulation of ash deposits on the boiler surfaces. Experiences obtained with the boiler referred to, however, have shown that difficulties of this kind can be precluded by liberal and appropriate furnace dimensions. Some two years of operation have shown that an ordinary soot blower installation is quite sufficient to keep the boiler surfaces clean. Only when large amounts of blast furnace gas are fired does a deposit form on the superheater tubes, which is difficult to remove by steam lancing, so that mechanical cleaning must be resorted to at suitable intervals.

In present-day practice boilers are nearly always equipped with economisers of small diameter tubing (32 mm. external and 26 mm. internal diameter), which is difficult to clean internally if silicate deposits should occur there. For such conditions a special indirectly heated economiser has been developed by the Svenska Maskinverken (Swedish Machine Works) concern. In this arrangement, outlined in Fig. 2, the feed-water is passed through a counter current heat exchanger, which forms part of the circulatory system of the boiler, hereby reducing the temperature of the circulating water to within 10 deg. above the temperature of the feed-water. The cooled circulating water is then reheated in the boiler, with the requisite heating surface taking the place of the usual economiser. From this heating surface the water heated to saturation point is then returned into the boiler drum.

Owing to the high specific heat transfer obtaining in the surface of the heat exchanger, its dimensions are small, and it is so designed as to permit ready removal of scale and sludge.

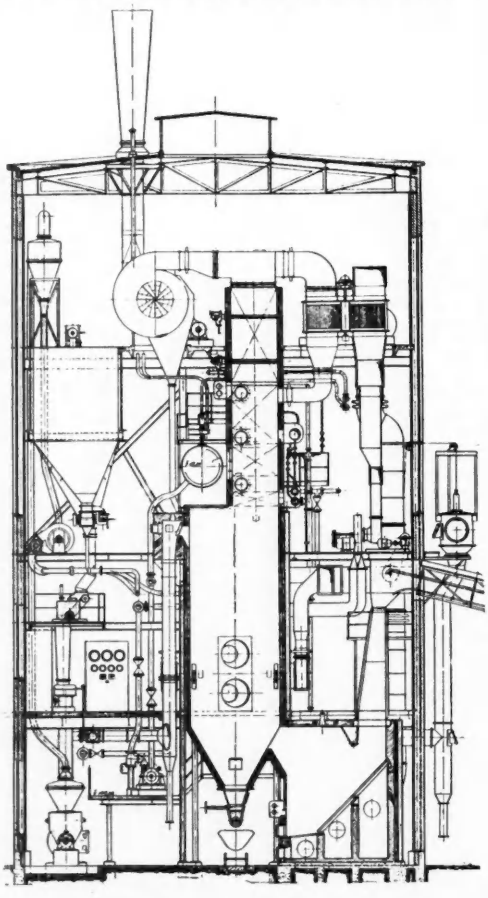


Fig. 1. **La Mont boiler installed in Swedish steelworks.** Max. output 30 t/h. Steam pressure 30 atm.g. Final steam temperature 425 deg. C.

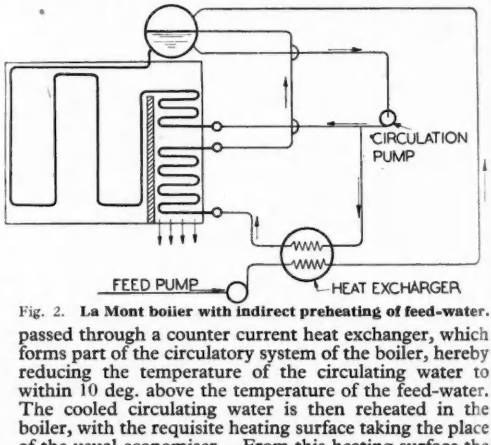


Fig. 2. **La Mont boiler with indirect preheating of feed-water.**

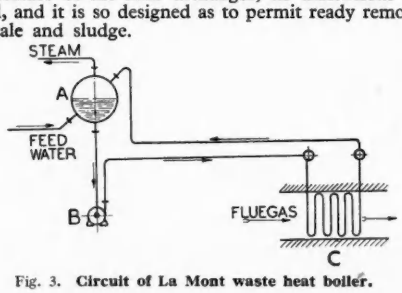


Fig. 3. **Circuit of La Mont waste heat boiler.**

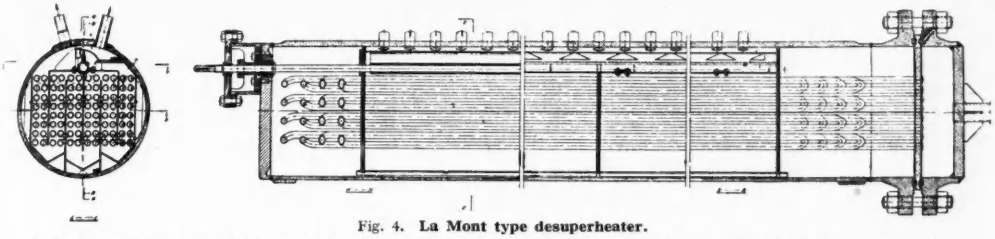


Fig. 4. **La Mont type desuperheater.**

La Mont boilers are highly suitable for the purposes of waste heat utilisation in cases where the boiler surface must be accommodated in the flue gas ducts of industrial furnaces (Fig. 3). An outstanding advantage of the La Mont principle in this respect is that the boiler heating surface may be located at considerable distance from the steam drum, and this also permits to connect several boiler heating surfaces located at various points to a common steam drum. Thus the steam drum and the circulating pumps may be placed in a central steam plant, with the boiler surfaces located at various points external to this plant. In a Swedish plant of this type no fewer than 15 individual boiler surfaces are connected in this way to a central steam collecting plant, thus affording centralised supervision of the entire plant.

A desuperheater of the surface cooler type to operate in conjunction with a La Mont boiler is shown in Fig. 4. In this design the cooling coils form part of the forced flow circuit of the boiler—that is to say, boiler water is employed as cooling medium, the steam to be desuperheated flowing over the outer surfaces of the tubing. The final temperature of the desuperheated steam is controlled by means of an internal damper device which controls the amount of steam flow over cooling coils. Desuperheaters of this type find application to controlled high temperature superheaters in which the final steam outlet temperature is maintained constant by providing an intermediate desuperneater between the two superheater sections.

In Fig. 5 is shown a centrifugal dust collector which is particularly suited to the cleaning of waste gases containing considerable amounts of dust, when the gas temperatures are too high to permit the employment of a conventional type of dust collector. Referring to Fig. 5, it will be seen that the dust collector is completely lined with La Mont evaporating tubes. This apparatus therefore combines the effect of dust collection with the generation of a sizeable amount of steam.

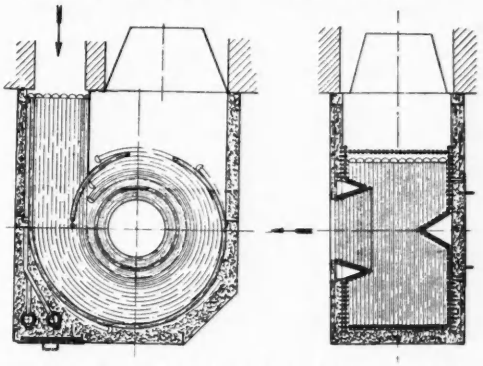


Fig. 5. **Centrifugal dust collector lined with La Mont tubes.**

The La Mont system can also be employed to advantage to boilers fired by wood chips or wood shavings. In this type of installation the grate is composed of an appropriate number of thick-walled La Mont tubes of small diameter, with the clearance between the tubes amounting to 8 to 10 mm. This tubing is arranged to form part of the circulating system of the boiler.

INDUSTRIALISATION OF SOVIET AZERBAIJAN*

By GEGAM ANTELEPYAN, Chairman of the Azerbaijan State Planning Commission.

THE fourth five-year plan envisages a large-scale building scheme for Soviet Azerbaijan. At present, we are tackling the problem of linking up the construction or expansion of hydroelectric and irrigation systems with the systematic development of several districts.

The construction of the Mingachaur hydro-electric power plant on the Kura river, about midway between Baku and Tbilisi is already under way. It will be second only to the Dnieprostroi power plant as regards capacity, and will double the power resources of the republic. Baku oilfields will thus be assured of an abundant supply of cheap electricity. A huge water reservoir, greater than Sevan Lake, will be built near the power plant. This reservoir will permit the irrigation of enormous areas which today cannot be cultivated. This will result in trebling the area under cotton, grain, and other agricultural crops. Preparations are being made to exterminate the malaria mosquitos which infest the region to be irrigated.

The next five years will mark the birth of a steel, iron, non-ferrous metal, and rubber industry in Azarbaijan. The industrial exploitation of the large deposits of the Dashkesan iron-ore fields has commenced. Ore will be shipped to the huge steel and iron works now under construction in Georgia and also to Sumgait, on the outskirts of Baku, where the foundations of a tube-rolling mill have just been laid. This undertaking will supply the Baku oilfields with all necessary types of piping. The alunite deposits in the proximity of the city of Kirovobad are to be exploited and the output will be transported to Sumgait where a new aluminium plant is to be built.

The construction of the first experimental plant for the manufacture of natural rubber from the Guayule plant, which grows in the southern regions of the republic, is nearing completion.

Great importance is also attached to improving the living conditions of the population of Azerbaijan. Work on municipal improvements is constantly proceeding in Baku, Nakhichevan, Stepanokert, Kirovobad and other towns of the republic. In five years' time, Azerbaijan will occupy a still higher place among the Soviet republics as an industrial country with highly developed agriculture.

*We have received this article by Gegam Antelepyan, Chairman of the Azerbaijan State Planning Commission, for exclusive publication in THE ENGINEERS' DIGEST. Although the short article does not deal with the engineering aspects of the projects, we have decided to publish it because of the magnitude of the projects and as a stimulus for the participation of our industry in the developments involved. At the same time, we have asked Mr. Antelepyan to supply us with full details of the technical program, for publication in our paper.

NEW UNIT TYPE MACHINE TOOLS.

By K. HEGNER. (From *VDI Zeitschrift*, Vol. 88, 1944, pp. 633-37).

THE design and construction of complicated special machine tools for a given task is a lengthy and often uneconomic undertaking, if hitherto followed methods of developing completely new types of machine tools are resorted to. Fundamental considerations in the rapid construction of machine tools for special purposes are reduction of the design phase to a minimum, rapidity of construction, and easy convertibility of the machine tool. These considerations can be adhered to only by separating the component parts of the special machine tool required into independent component groups, such as tool holder, work piece support, mechanical drives, and certain ancillary components, as will be seen from Fig. 1. All these components have been standardised

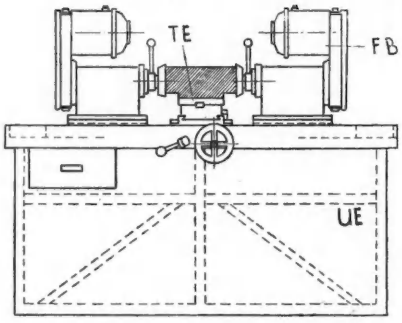


Fig. 1. **Composite special machine tool comprising milling units.**
TE table unit ; FB, milling unit ; UE, support unit

in certain ranges. By producing these unit components in series, rapid and simple manufacture is ensured.

Owing to war time exigencies, standardisation of the component units has had to be limited to the aspects of their combination into a single machine to the unified dimensions of tool holders and work piece supports, rather than to the unified design of the component units as such. In the first stage of this development the component units therefore represented adaptations of well-tried existing designs. For boring and milling purposes, which are the two most frequent machinery operations, two kinds of unit types were developed. In the first of these two groups, the boring-units and milling-units etc., constitute self-contained machines as far as tool carrier and feed mechanism are concerned, with the work piece support of standardised design as the only component unit to be added. In the second group the tool carrier, the work piece support and the feed mechanism are entirely independent and separate component units which can be combined in any desired manner. These composite machine tools can (1) be employed as independent units ; (2) they can be combined into special machine tools ; (3) they can also be used as individual units in the production line ; or (4) they can be used in continuous production of the conveyor type.

The composite unit will be used as independent unit in place of a machine tool of the customary type, especially in cases where simple repetition work is concerned. In this application the composite unit offers the advantage that it represents a small machine tool equipped with only those mechanisms essential for the purpose in view, and nothing else. Also, this unit can be easily adapted to other purposes by the substitution of a few elements such as gears or pulleys. It is self-evident that a small machine tool of this composite type is lower in cost and can be more rapidly built than a universal tool equipped with a choice of gears for all kinds of machining operations.

The special advantages of composite units lie in their combination into a special machine tool. In this application the units are generally placed opposite the faces of the work piece to be machined, a concrete foundation or a cast or welded base plate uniting the composite units into a single machine tool, as exemplified by Figs. 1, 2 and 3.

In the production line which represents the simplest means of carrying out mass production, the individual phases of the production process are carried out by machine tools arranged in proper sequence. The work piece is then transported from one machine to the other machine. This requires fixing to and subsequent removal of the work piece from the work piece table of each of these machines in turn. Replacing the machine tools hitherto used in production lines by composite units of appropriate speed and feed rates, etc., enables all superfluous features present in ordinary machine tools to be eliminated (Fig. 4). It goes without saying that a production line may be composed of both single composite machine tools and special tools built up of composite units. The ideal form of mass manufacture is the continuous conveyor type production line, in which the work piece tables of the individual machine tool units are eliminated by fixing the work piece to a movable table moved in conveyor fashion past the individual machine tool units. This movement may be circular or straight-forward. In either case each unit is designed for a specific task. In this arrangement standardisation extends also to the work carrying table, etc.

In the circular arrangement the work pieces are placed on turn-tables encompassed by the requisite machine tool units. The movement of the work piece

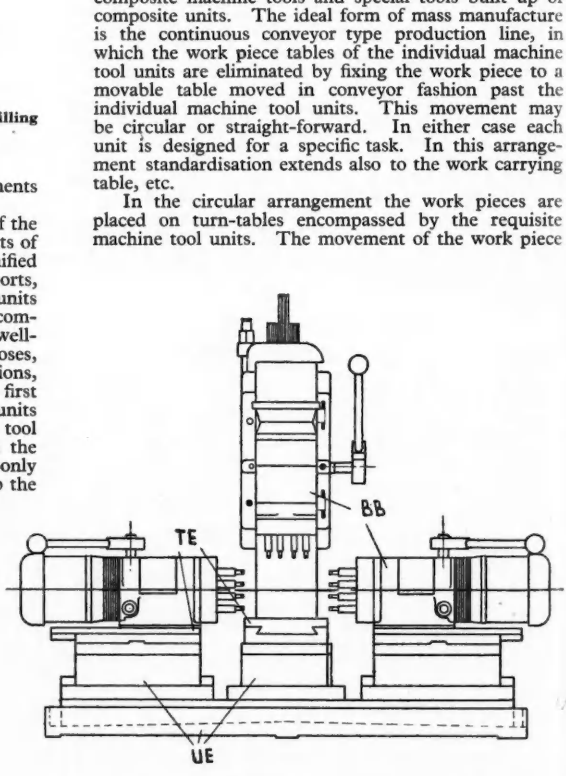
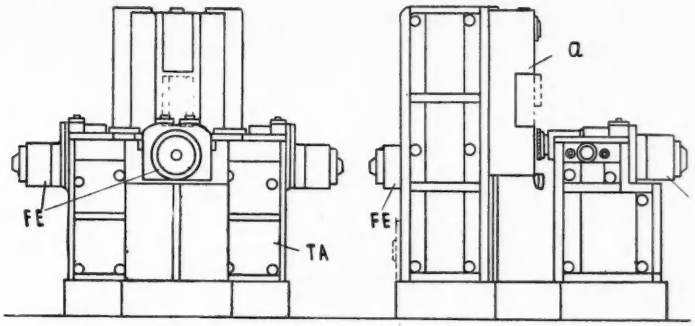


Fig. 2. **Composite special machine tool comprising boring units.**
TE, Work piece table unit ; BB, boring unit ; UE, support unit (cast iron type).



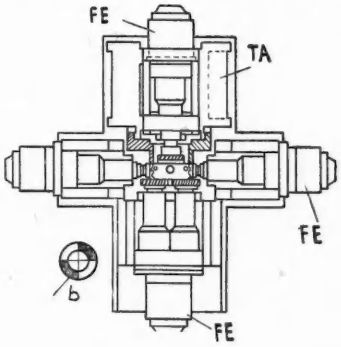


Fig. 3. **Composite special machine tool comprising milling units.**

FE, Milling unit; TA, box-type girder supports.

a. Work-piece holder.

b. Position of operator.

from station to station may be effected manually or automatically. In the case of work pieces requiring machinery times of considerable length, the straightforward movement is preferred. For this purpose the work pieces are carried on standardised carriages which are passed to the machine tool either by hand or automatically, these carriages being locked in position during the machinery process (Fig. 5).

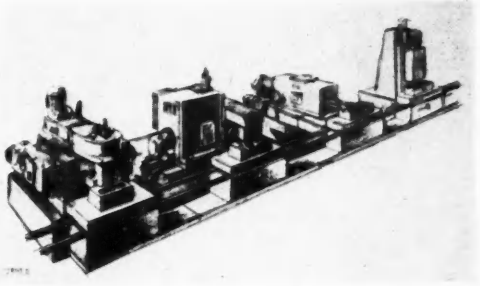


Fig. 5. **Conveyor type continuous production with station arranged in straight line.**

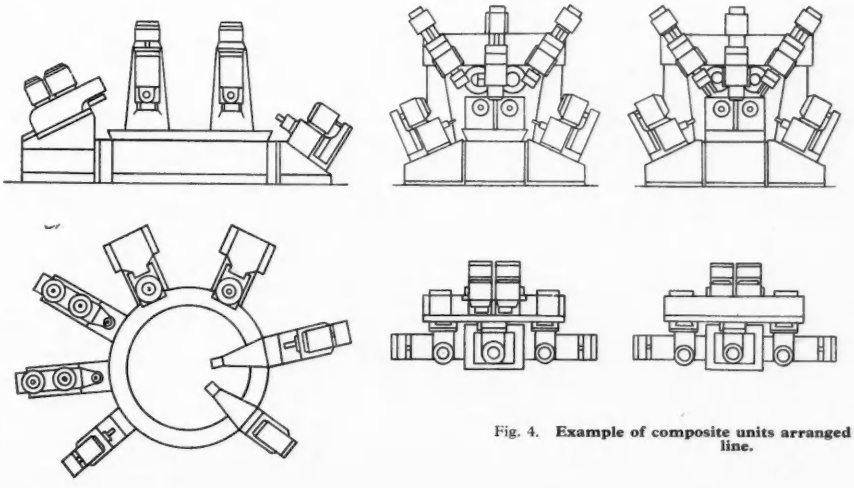


Fig. 4. **Example of composite units arranged in production line.**

NEW BURNER TYPE WITH MECHANICAL AND TWO-STAGE AIR ATOMIZATION WITH FLAME LENGTH CONTROL FOR OPEN-HEARTH FURNACES.

By S. S. BERMAN. (From *Stal*, Moscow, No. 9/10, 1944 ; pp.20–24.)

AT a steel works of the People's Commissariat equipped with three open-hearth furnaces varying from 13 to 95 tons capacity, a new burner type, developed by Shukov in co-operation with the Dniepopetrovsk Metallurgical Institute, has been installed. Further installations of this burner type have been made in conjunction with two 50-ton open-hearth furnaces of another steel works. This new burner type was developed to meet the following requirements :—

(1) Ability of the burner to operate at the usual air or steam pressure of 4–5 atmospheres.
(2) Attainment of a very high degree of oil atomization.
(3) Wide load range controllability without deterioration in the degree of atomization.
(4) High degree of flame stability.
(5) Possibility of effective flame length control.

A general view of the new burner type is given in the accompanying illustration.

The oil is passed through the internal tube of the burner chamber (1). The discharge from this tube is controlled by means of an internal valve carried at the free end of the valve stem (3) and operated by means of the handwheel (5).

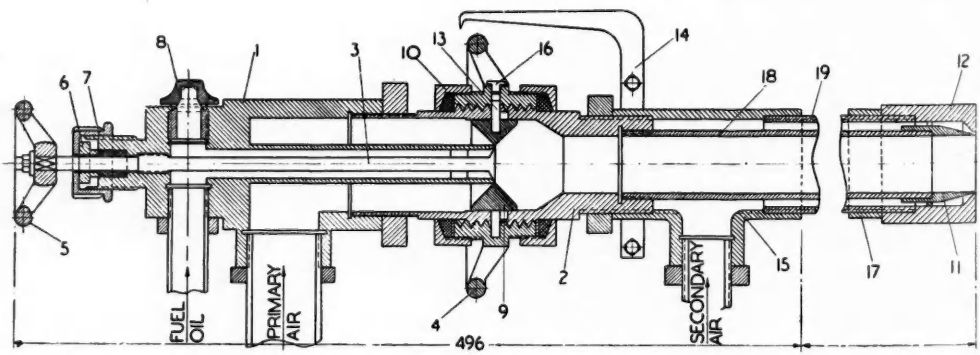
The primary air at high pressure or steam is admitted into the annular space of the burner chamber, from which it is discharged in the shape of a thin annular jet intermingling with the fuel spray. The rate of primary air supply can be adjusted by shifting the orifice canal in the threaded bush (9), which can be rotated by means of the handwheel (4). The mixture of fuel and primary air is passed into the tube (18), and hence into the nozzle (11). The latter is arranged concentrically in the tube (19), secondary air or steam being admitted into the annular space between tubes (19) and (18). The rate of secondary air admission is controlled by means of a valve in the air supply line (not shown).

The chief advantages of this burner are :—

(1) Satisfactory atomization of the fuel oil.
(2) Wide control range without impairment of the atomization.
(3) Stable high velocity flame.
(4) Wide range control of flame length.

Burners of this type were fitted to a 50-ton open-hearth furnace used for the making of carbon and alloy steel. These burners were in continuous service for a long period and gave satisfactory service in spite of considerable fluctuations both in the air supply pressure (ranging from 2 to 6 atmospheres) and in the oil pressure (ranging from 3 to 5½ atmospheres). Owing to the good results achieved, burners of this type were also fitted to a 95-ton open-hearth furnace. It was found that the time required for the melt down was 40–48 minutes less compared with the burners previously used, and the time of working the heat was shortened by 16–39 minutes, which resulted in a time saving of 1 hr. 5 min. to 1 hr. 19 min. per charge. Also, the carbon loss per hour was reduced by approx. 0·17 per cent. Similar results were obtained in the operation of one 13-ton and two 50-ton furnaces.

The fuel saving effected by the introduction of the new burner type was found to be some 6–7 per cent with the 50-ton and 95-ton furnace, while it amounted to 15–26 per cent with the 13-ton furnace.



Burner for open-hearth furnace.

1. Air inlet chamber
2. Mixing piece
3. Valve stem
4. Handwheel for air control
5. Handwheel for fuel control
6. Stuffing box gland
7. Cap
8. Plug
9. Air nozzle
10. Stuffing box
11. Fuel nozzle tip
12. Air nozzle tip
13. Pin
14. Ring with pointer
15. Secondary air inlet
16. Plug
17. Counter nut
18. Tube
19. Tube

A SHORT NOTE ON SUPER-DURALUMIN.

By D. P. CHATTERJEE. (From *The Quarterly Journal of the Geological, Mining and Metallurgical Society of India*, Vol. 17, No. 2, 1945 pp. 53-62.)

THE constituents of super-duralumin are almost similar to ordinary duralumin, except the increased percentages of copper and silicon in the alloy. Typical composition is given below :—

Constituents.	Super-Duralumin.	Duralumin.
Copper	4·62 per cent	3·52 per cent
Iron	0·62 ,,	0·70 ,,
Manganese	0·58 ,,	0·41 ,,
Magnesium	0·47 ,,	0·44 ,,
Silicon	1·02 ,,	0·51 ,,
Zinc	Trace.	Trace.
Sodium	Trace.	Trace.
Aluminium	Diff.	Diff.

Another variety of "duralumin" has also been studied, details of which will be described subsequently. The composition of this third variety is slightly different from either of duralumin and super-duralumin. Typical composition is as follows :—

Constituents.	P. C.	Constituents.	P. C.
Copper	4·60 per cent	Silicon	0·89 per cent
Iron	0·62 ,,	Zinc	Trace.
Manganese	0·58 ,,	Sodium	Trace.
Magnesium	0·44 ,,	Aluminum	Diff.

CASTING OF INGOTS AND FABRICATION.

Super-duralumin ingots are cast in the same way as ordinary duralumin ingots. A hardener of the composition 50/50 aluminium and copper is first prepared, which is subsequently diluted with the addition of aluminium to bring the melt to the required composition, other alloying elements are subsequently added. Addition of manganese is effected—through an alloy of manganese-copper (70 per cent Cu. and 30 per cent Mn.), silicon—through silicon metal (99·5 per cent purity) and magnesium—through electrolytic magnesium metal (st cks of 99·9 per cent purity). After proper melting the alloy is generally modified with a mixture of sodium and aluminium fluorides. Various types of ingots are cast depending on the nature of subsequent fabrication : strip ingots for sheets, round ingots for bars, flats, and different intricate designs.

Samples of rods approximately 2¼ in. round which have been studied for heat-treatment, were obtained by hot pressing of 6 in. round ingots. Cold ingot 6 in. round was charged in an ordinary coal-fired reverberatory type furnace, maintained at a temperature of 430 deg.–450 deg. C. The temperature of the ingots was slowly and steadily raised to 450 deg. C, and maintained at the temperature for 2 hours nearly, subsequently removed and extruded satisfactorily. Details of time-temperature relation are shown graphically in Fig. 1. In the case of mass-production, it is preferred that a furnace with slanting hearth is used, so that ingots are charged at one end, roll over the bed and subsequently are removed for hot working, from the other end. During rolling, the billets get uniformly heated and soaked, at the desired temperature. Extrusion resulted in a reduction in area of over 82 per cent.

HEAT TREATMENT.

A small electric muffle furnace with adjustable resistance was used in this connection. The cold furnace was charged with cold test-pieces and switched on. Resistance was so adjusted, that the rise in temperature of the furnace and the test-pieces were uniform, slow and steady, as far as practicable. Temperature was raised to 480 deg. C. and maintained in the region of 480 deg. ± 2 deg. C. Test-pieces were turned round every quarter of an hour for uniform soaking. Details of time-temperature relation are shown in Fig. 2.

Hot pieces were quickly removed and quenched in oil, maintained at room temperature by circulating water round the quenching tank. The test-pieces were allowed to remain in oil for 1¼ hours, and subsequently removed for accelerated age-hardening.

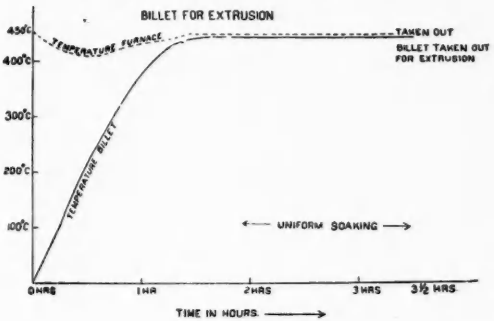


Fig. 1

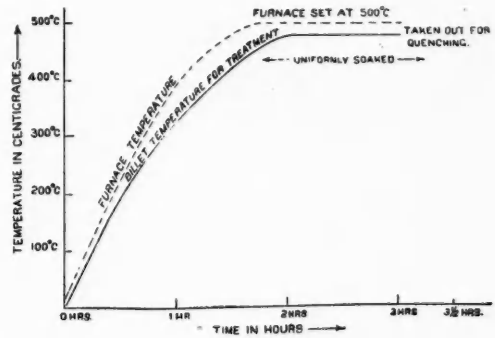


Fig. 2

HARDNESS OF TEST-PIECES.

Condition of Test pieces.	Hardness. Rockwell 'F' Scale 1/16 in. steel ball with 60 kg. load.	Brinell 10 mm. ball with 500 kg. load.
	Extruded Material.	
Test No. 1	62	58
Test No. 2	64	60
Test No. 3	64	60
	Quenched Material.	
Test No. 1	82	82
Test No. 2	82	82
Test No. 3	84	87

Quenched samples after being withdrawn from the quenching tank, were tempered in oil bath maintained at 178 deg. ± 2 deg. C., for accelerated age-hardening.

The following properties were developed after a period of 5 hours' accelerated age-hardening.

Oil quenched at 480 deg. ± 2 deg. C. and age hardened at 178 deg. ± 2 deg. C.

PHYSICAL TEST RESULTS.

No. of Test	Proof stress 10 per cent Tons/per sq. in.	Breaking stress Tons/per sq. in.	Elongation per cent	HARDNESS. R.F. 1/16" ball & 60 kg. load.	Brinell 10 mm. ball 500 kg. load.
1 ..	20·0	25·2	8·7	93	112
2 ..	20·2	25·8	9·0	94	114
3 ..	21·0	26·2	9·0	94	114
4 ..	20·0	26·0	8·8	95	116
5 ..	20·0	25·8	9·0	94	114

The test result being not very satisfactory, so far as the Yield (Proof stress) and Break load are concerned, another experiment was conducted. Samples were uniformly heated to 480 deg. C. as before, soaked at temperature and then more drastically quenched in cold water. Quenched samples were subsequently age-hardened in an oil bath at 178 deg. ± 2 deg. C. Some of the sample-pieces were accelerated age-hardened for 8 hours and some for 24 hours.

HARDNESS DEVELOPED ON ACCELERATED AGE-HARDENING.

(Sample water quenched at 480 deg. ± 2 deg. C. and accelerated age-hardened at 178 deg. ± 2 deg. C).

Period of Age-hardening.	HARDNESS. R/F.	B.H. No.	Period of Age-hardening.	HARDNESS. R/F.	B.H. No.
After quenching	86	93	16 hrs.	94/95	114/117
4 hours	89/90	100/103	20 hrs.	94/95	114/117
8 hours	91/92	106/108	22 hrs.	96/97	121/123
12 hours	91/91	106/108	24 hrs.	96/97	121/123

Rockwell 'F'—$\frac{1}{16}$ in. Steel ball with 60 kg. load.

Brinell—10 mm. ball with 500 kg. load.

PHYSICAL TEST RESULTS.

(Water quenched at 480 deg. ± 2 deg. C. Accelerated age-hardened at 178 deg. ± 2 deg. C.)

Test No.	Period of Age-hardening.	Proof 1 per cent stress tons per sq. in.	Breaking stress tons per sq. in.	Elongation per cent.
1 ..	8 hours	22·4	30·0	9·5
2 ..	8 hours	23·0	30·5	9·5
3 ..	8 hours	23·0	31·0	9·0
4 ..	24 hours	24·0	32·0	9·0
5 ..	24 hours	24·5	33·0	8·5
6 ..	24 hours	24·5	32·5	8·8

The next thing which was studied, was the effect of using higher temperature both for solution and accelerated age-hardening treatments. The same sizes of Test Samples were taken and the following treatments applied :—

One batch was water quenched at the same temperature as previously, 480 deg. C., but accelerated age-hardened at 196 deg. C. for 24 hours.

Another batch was water quenched at 510 deg. C., and accelerated age-hardened at 196 deg. C. for 24 hours.

Three samples from each of the two batches water quenched at 480 deg. C. and 510 deg. C. were age-hardened at room temperature for 168 hours.

Water quenched at 480 deg. ± 2 deg. C. and accelerated age-hardened at 196 deg. ± 2 deg. C. for 24 hours.

Development of hardness, with time (aging) in the case of normal and accelerated age-hardening, with differently treated specimens are shown graphically (Fig. 3).

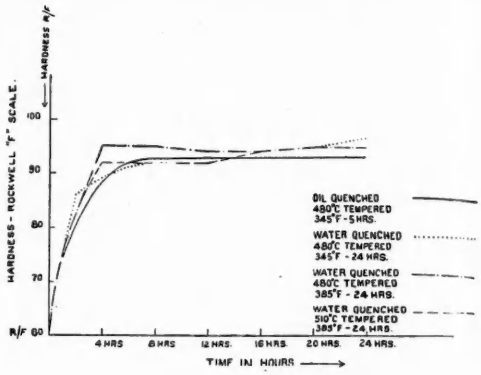


Fig. 3

It was observed that the best properties were obtained with the solution and accelerated age-hardening treatments at lower temperature, for shorter periods.

SHEETS AND STRIPS.

According to the definition of the terms "sheets" and "strips," the difference between the two lies in the thickness and width only. Super-duralumin sheets and strips were obtained by cross rolling (diagonal feeding) as well as by straight rolling of cast strip ingots having a thickness of about 1/25 in. The ingot was cropped from the top to the extent of 8-10 per cent of the total length of the material, for discarding the segregated and porous parts of the material. It was charged into the gas fired furnace, the temperature was increased up to 480-490 deg. C. The ingot soaked for 1½ hours and then removed for hot rolling were giving in the beginning a few light passes. Every precaution was taken not to reduce the thickness, by more than 40 per cent, in one operation. Finishing temperature was maintained, well above the re-crystallisation range, to avoid an unnecessary straining on the material as well as to allow spontaneous re-crystallisation to take place. The stock was reduced to ·28 in. thickness by hot rolling, and finally finished to different thicknesses by cold rolling, with intermediate annealings at 400-430 deg. C. During intermediate annealings, the material was handled very carefully, lapped into coils, and allowed to remain in the furnace till the temperature dropped down to about 150 deg. C. It was observed that well annealed material can undergo over 60 per cent reduction in area by cold rolling quite satisfactorily in one cycle of rolling. Fully annealed material gave a hardness of V.P.N. 42-46 and after cold rolling, hardness went up to 135-140 V.P.N.

Different sizes of material were studied for mechanical strength under different conditions, e.g., cold rolled annealed water-quenched, followed by accelerated age-hardening.

PHYSICAL TEST-RESULTS.

A. Cold rolled material. Tested in the rolled condition, standard size parallel-end test pieces were made with gauge length 8 ins. parallel length not less than 9 ins. and total length about 18 ins.

PHYSICAL TEST.

Gauge Thickness.	Hardness V.P.N.	Break Tons per sq. in.	Elongation per cent.
		22·0	8·0
4 B.G.	98	21·0	8·0
·247 in.		22·5	7·5
		22·0	4·5
6 B.G.	105	23·0	5·0
·20 in.		23·5	5·0
		24·0	5·0
12 B.G.	115	24·0	5·5
·10 in.		23·4	4·0
		26·0	3·0
16 B.G.	120	27·2	3·0
·063 in.		27·7	3·0
		27·0	3·0
19 B.G.	120	27·5	3·5
·045 in.		27·0	3·0
		27·0	2·5
20 B.G.	125	28·6	2·0
·038 in.		27·5	3·0
25 B.G.	130	28·5	2·0
·022 in.		28·0	2·5
27 B.G.	130	27·5	2·0
·018 in.		27·0	3·0

B. Water quenched at 500 deg. ± 5 deg. C. and accepted age-hardened at 180 deg. ± 5 deg. C. in oil bath.

(Parallel-end test pieces of the same size as before.)

PHYSICAL TEST-RESULTS.

Gauge Thickness	Hardness V.P.N.	Proof stress 15 per cent Tons/sq. in.	Breaking stress Tons/sq. in.	Elongation per cent.
	125	25·0	28·2	8·0
20 B.G.	130	25·0	28·5	8·0
	125	25·5	29·0	9·0
	130	24·0	27·0	7·5
25 B.G.	135	25·5	30·0	8·0
	130	24·0	27·5	8·0

C. Water-quenched at 500 deg. ± 5 deg. C. and accelerated age-hardened at 200 deg. ± 5 deg. C. in oil bath.

(Parellel-end test pieces as before.)

PHYSICAL TEST-RESULTS.

Gauge Thickness	Hardness V.P.N.	Proof stress 15 per cent Tons/sq. in.	Breaking stress Tons/sq. in.	Elongation per cent.
	130	24·0	29·5	6·0
19 B.G.	135	25·0	30·5	6·0
	132	25·0	29·0	8·0
	135	24·0	28·0	6·0
27 B.G.	130	24·0	28·5	7·0
	130	25·0	29·0	6·5

D. Water-quenched at 500 deg. ± 5 deg. C. only. (Pulled immediately after water quenching.)

PHYSICAL TEST-RESULTS.

Thickness	Hardness V.P.N.	Proof stress 15 per cent. Tons/sq. in.	Breaking stress Tons/sq. in.	Elongation per cent.
		9·0	18·0	17·0
25 B.G.	61	9·5	20·0	17·5
		12·0	21·0	21·0
27 B.G.	56	11·8	20·7	21·0

WIRES.

Quarter-inch round rods, were used for the manufacture of super-duralumin wires of different diameters, 6, 12, 15, and 18 S.W.G. Material was annealed as before and cold drawn through a draw-plate, successively with intermediate annealings to give the finished sizes of the wire as required. Cold deformation induces the grains to be refined so that one original grain exhibits a mixture of orientations after cold work. This kind of grain refinement differs largely from that obtained by annealing at low temperature. Intermediate annealings were always carried out at 400-430 deg. C. well above the re-crystalization temperature. The speed of travel through the drawing plate and drawing dies, was carefully adjusted so as to keep the tension on the wire not to exceed 70-75 per cent of ultimate tensile stress.

Size Gauge.	Breaking stress tons/sq. in.	Size S.W.G.	Breaking stress Tons/sq. in.
	38·0		40·0
6 S.W.G.	38·5	15 S.W.G.	41·0
	38·0		40·0
	40·0		42·0
12 S.W.G.	40·0	18 S.W.G.	42·0
	38·8		44·0

FORGINGS.

Different intricate designs were hot stamped by a stamping press. The best forging temperature was found to vary between 480-510 deg. C. avoiding any hot-shortness. Round bars were parted to sizes, heated in a small heating furnace and hot stamped, with top and bottom dies fixed in the press. The material flowed well between the dies during stamping. Thus forged stampings were not heat-treated to develop their highest mechanical properties, but the stamping operations were finished at the lowest possible temperature, in order to obtain the higher strength. Cold compression tests were carried out and the stampings were found to resist crushing loads of more than 120 tons per square inch.

WHAT HAS HAPPENED TO MOTION AND TIME STUDY?

By L. C. PIGAGE, Assistant Professor of General Engineering, Purdue University, Lafayette, Indiana.

MOTION and time study is not a new subject in the industrial field, but it has become of increasing importance during the past war years. No doubt this importance was due to the all-out war effort made in the United States and in other countries. The need of producing ever increasing quantities of war equipment at a reasonable cost and of the greatest possible economy in national expenditure, gave the subject momentum.

The advance made in industrial applications of the subject can be said to be in three phases :—

1. Extension of the knowledge of the subject to a larger number of people.
2. Extension of the fundamental technique used.
3. Extension of the field of application.

SUBJECT MATERIAL MADE AVAILABLE TO MORE PERSONNEL.

No one will hesitate to recognize that the fundamental technique of motion and time study is simple; but, with the extension of the number of symbols, of the use of films, and of stop-watch study, a certain amount of mysterious feeling and distrust has developed with the majority of employers. This feeling is due to the high sounding terms used by time study engineers together with a maze of equipment and charts, and to the ultimate working condition to which the employees have been subjected.

The placing of the country first on a defence, then on a war basis, asked all employers for increased production with a curtailed labour force. The labour problem increased as the seriousness of the world conflict progressed. All types of employment were concerned.

More interest in motion and time study as a means of increasing production, and of providing higher pay for employees originated from these conditions. The Engineering-Science-Management Training Programme under the joint sponsorship of the U.S. Office of Education and colleges or universities assisted materially in laying the foundation. Courses in elementary and advanced motion and time study were introduced. The

courses consisted of one or two three-hour class meetings per week for a total of fifty or seventy-five hours. Usually the shorter courses were for those not directly engaged in time study work.

Shortly after the introduction of this training, the industry became very interested and encouraged all first-line management personnel to avail themselves of this opportunity. Courses were quickly arranged for:

1. Executives. 2. Supervisors and/or foremen. 3. Group leaders. 4. Operators. 5. Union stewards and/or officials.

The classes were established for any one type of personnel separately or for a combination of all five. The author successfully trained personnel in class combinations of all types. The increasing demand for such training expressed by union stewards and/or officers shows the soundness of this idea. In numerous cases large improvement resulted in management-union relationship from the latter group's better understanding of the principles.

According to the situation the classes were held in plants, a neutral building, or at the university. Each course usually consisted of a presentation of the basic first fundamentals. In so far as possible the subject material was built around the existing practice of the plants represented by those who attended the course. In this way chaos was avoided and good help could be given to individuals in their daily work. Furthermore, each attendant was asked to apply the principles to a problem in the plant, which he could select.

In the case of several companies—steel strip mill, band instruments, steel casting, and aircraft engine parts—tentative accounting indicated that even with payment of all expenses, including time spent by the employee in the class, the acceptance of some problem solutions by the company concerned more than paid for the costs of the course. This does not include any suggestions received from the trained personnel after completion of the course. A further investigation also revealed that the majority of the acceptable projects came from personnel not directly engaged in time study work for the company.

With the cessation of hostilities and the government no longer sponsoring such training, numerous companies are proceeding with it under their own direction or in co-operation with educational institutions. The scope of the courses has been extended in a large number of cases to include all operators in the plant.* When this is attempted usually the subject material is simplified by limiting it to symbols, special forms, and equipment as used in regular motion and time study departments.

NEW FUNDAMENTAL TECHNIQUES.

In recent years the fundamental techniques of motion and time study have been:

1. The promotion of the use of standard data.
2. A plant-wide application of wage incentives.
3. Standards for operation, flow, and multiple activity process charts.†
4. Rating or levelling.‡

The idea of standard data is not new. Its greatest impetus developed from the hastily conceived plant-wide application of wage incentives. In many cases these incentive plans have been installed without accurate standards of measurement. This lack of accuracy made itself felt in the selection of the unit base or in the analysis of factors involved in the respective tasks. No doubt the plans did "work" and secured to varying degrees the increased production at fairly stable labour costs, and yet increased the pay for the employee. With the return to peace-time competitive conditions, however, the inequalities of proper cost allocation and job-equity pay within a plant will be evident and will be aggravated by these improperly conceived plans. Standard data are proposed as a means of establishing measurement on both direct and indirect as well as repetitive or highly variable work, that will give the true relationship existing for all labour items entering into the cost of a product. This standard will then enable some individual accounting for each person's performance and keep it separate from the results of some other individual's accomplishment.

Such a muddle of the pay of various persons can be very serious, especially in peace time, when business fluctuations exist as in comparison with times of all-out effort in war. The ratio usually established between some factor for direct labour to one for indirect labour, as used in incentive plans, does not change uniformly with the volume of the company's business.

The author feels there will be an attempt either to patch up wage incentive plans or to withdraw them altogether. In either case serious obstructions will be met with in one form or another, as a consequence of the dissatisfaction of the employees.

As in any other field of endeavour various systems have been promoted to assist the personnel while their difficulties were growing with expanding production. These systems assume the form of abbreviations, symbols, charting, and the like. Motion and time study work is no exception in this respect. There has been a certain amount of accepted nomenclature or characters, but variations have crept in. This is especially so with the more complex problems to be analysed in the progress of industrial processes

The American Society of Mechanical Engineers have accepted proposals for use in the construction of operation, flow, and multiple activity charts. Tentative drafts have been made and submitted to interested parties. As soon as an agreement can be reached, the final draft will be presented as a standard. Considerable good will come from this in that the exchange of scientific material on motion and time study will then be more comprehensive.

When one examines the numerous techniques in time study work, a reasonable and stable procedure capable of withstanding attack can be obtained for all parts except rating or levelling. Rating has been and still continues to be a matter of judgment. The extent of variation of basis for this judgment rests with the systems considered. Skill and effort are factors judged in rating by some observers. Others include working conditions and consistency of the time values observed in a study. Still others promote the idea of comparison of observed pace with the observer's mental image of a reasonable pace. In most of these practices an attempt has been made to define the acceptable standard of the factor being judged. Degrees of variation above and below these standards have been added for guidance; but the written guide allows the observer considerable freedom of interpretation of what is in the mind of the person defining the standard with its corresponding degrees of variance.

With the introduction of films for training personnel in rating there originated the idea of using a film, in loop form, which shows the pace acceptable in a company as standard to management and labour. When comparing this method with written definitions any variance in interpretation of the expected standard by individuals is reduced to a minimum.

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* RITTENHOUSE, J. F., Jr., "Motion Study for Foremen and Shops Stewards," *Factory Management and Maintenance*, March, 1945, Vol. 103, No. 3, page 98. KESSLER, I. K., "Practice Work Simplification," *Factory Management and Maintenance*, August, 1945, Vol. 103, No. 8, page 120.

† "Multiple Activity Process Chart," "The Standards Column," *Mechanical Engineering*, December, 1944, Vol. 66, No. 12, page 46.

‡ MUNDEL, M. E., "An Analysis of Time Study Rating Systems and Suggestions for a Simplified Systematic System," *Industrial Engineer*, 1944, Vol. IV, No. 4, page 21. Also personal conference with Dr. Mundel. PRESGRAVE, R., *The Dynamics of Time Study*, The University of Toronto Press, 1944, Chap. 5, 6, 12, 13, 14, 15.

The originator of this plan,‡ Dr. M. E. Mundel of Purdue University, further developed the idea to have one such standard loop of some one operation in a plant to serve as standard for all jobs. With this standard the rate of activity of all other jobs can be compared. In order to compensate for differences between the jobs and the standard, factors similar to those used in job evaluation are employed. Dr. Mundel suggests that these differences can be classified in five groups with degrees of each :

1. Personal
   Involving (*a*) Comfortable room conditions, or
   (*b*) Hot room conditions.
2. Amount of body used in task.
   Involving (*a*) Fingers used loosely.
   (*b*) Wrist and fingers.
   (*c*) Elbow, wrist, and fingers.
   (*d*) Full arm, elbow, wrist and fingers.
   (*e*) Some trunk, arm, elbow, etc.
3. Eye-hand co-ordination requirements
   Involving (*a*) Rough work mainly feel.
   (*b*) Moderate vision.
   (*c*) Constant but not close.
   (*d*) Controlled motions, fairly close.
   (*e*) Fine and close.
4. Handling or sensory requirements
   Involving (*a*) Can be roughly handled.
   (*b*) Can be squeezed and controlled.
   (*c*) Requires careful handling.
   (*d*) Fragile.
5. Weight
   Involving grades of weight handled in classes of 0 to 1 ; 1 to 2 ; 2 to 5 ; 5 to 10 ; 10 to 25 ; 25 to 50 ; and 50 to 70 lbs.

The procedure is to rate, while timing, the activity shown as a percentage of that for the standard loop. No account of the difficulty or difference between the job being studied and the standard is considered during the rating. Then, at some time before leaving the scene of the job being studied, the various degrees of job factor differences, as compared with the standard, are determined. These differences may be an additive or subtractive percentage of the actual time observed depending on the standard used. The differences also include the allowances for requirements of the operator's time not expressed in the method of performing the work. These differences can be applied,—and it is advisable to do so,—to the individual elements of the job rather than to the job as a whole.

When discussing the above plan with industrial personnel a suggestion has been made in several cases to have three standards all related. They would be for light, medium, and heavy work. It is claimed that the use of these three standards would aid in overcoming the large transition to be made by the rater from a job in one class to a standard which may be in another class of work. With this view in mind, such a suggestion is being carried out in some plants adopting the plan.

FIELDS OF APPLICATION OF MOTION AND TIME STUDY.

All fields of human endeavour in which goods or services are performed for others can be considered as making up the industrial structure known to-day.

Motion and time study has been applied to processing problems as found in the fabricating industries, and industrial concerns in which metal processing and assembly is the major work. Most illustrative applications published have dealt with small hand-assembly operations. Due to these illustrations, no doubt, little progress had been made in other fields of endeavour prior to the war. But, as pointed out previously, the results which could be expected from special motion study have given the momentum necessary to attempt applications in ever greater fields of human endeavour.

The need for greater production with limited labour force caused the spread of the application of principles of motion economy to wide fields, heretofore overlooked or neglected. The greatest efforts have been made in :

1. Heavy industries. 2. Agriculture.
3. Domestic tasks. 4. Military processes.

The application of methods and work studies in heavy industry has been attempted over several years. During the past few years a very successful training was carried on at a steel strip mill. It was necessary to provide for a parallel manipulation with reference material used in the training. The available reference material deals with hand operations. By a continual replacement of description of motions of each hand, as would appear in such hand operations with an operator and his helper (or machine), the principles of motion economy were successfully presented and used by the personnel attending the training sessions.

Perhaps the greatest achievement of recent years has been in agricultural work. In the later part of 1942 a National Project in Farm Work Simplification was instituted by the government, and a laboratory was established at Purdue University. A grant was made with the understanding that research into the simplification of farm work on a co-operative basis would be carried out together with other land-grant education institutions.

The general procedure assumed followed two trends. One trend was to encourage research in methods to be carried on by special assignment of personnel at the colleges. The other was the training of state farm agents in the principles, with the understanding that they would introduce such material to rural area groups. In each case publications for general consumption and encouragement to follow the practices proposed, were issued from time to time concerning projects already completed. To date there are available approximately one hundred publications in the form of bulletins, magazine and journal articles, or films. Hardly any job on a farm could be found which had not yet been studied, and the improvement of which had not been published.

With the close of the agreement the work will not cease. The benefits recognized have been solidly implanted and plans are completed to continue the project under individual institutions with a free exchange of results.

To further supplement the study of farm work simplification, several industrial organisations have done considerable work, or are promoting it in conjunction with their products. General Electric Company, Westinghouse Electric Corporation and Sinclair Refining Company are three industrial companies who have made valuable contribution to the promotion of farm work simplification. The contributions have been in the form of films or project study contests.

The farm work simplification idea has spread to domestic tasks. Plans are under way to develop courses in home economic education in which principles of motion economy will be presented. This has been greatly encouraged by a considerable number of demands for trained personnel. Positions requiring the knowledge of principles of methods are home economic county agents, interior decoration agents in home furnishing companies, and designers of home appliance manufacturers ; among these are also a few openings for women.

The other field, military processes, has developed to the point that the military departments have recognized that training in the principles of motion economy should become a necessary part in their activities. Mr. A. H. Mogensen§ and others have done a large amount of training of military personnel in the past few years. The applications made by these trained personnel have convinced the military officials that such work cannot be neglected.

§ MOGENSEN, A. H., "What the Works Manager Should Do About Work Simplification," Proceedings of the National Time and Motion Study Clinic, *The Industrial Management Society*, Chicago, Illinois, 1944, page 47.

CHROME — MANGANESE — TITANIUM AND SILICON — MANGANESE — MOLYBDENUM STEELS.

By M. P. BRAUN. (From *Stal*, Moscow, Nos. 9/10, 1944, pp. 89-90).

A CHROME-MANGANESE-TITANIUM and a silicon-manganese-molybdenum steel were both investigated in order to ascertain whether they were suitable as substitutes for chrome-nickel, chrome-nickel-molybdenum and tungsten steels.

The steels tested had the following compositions :

Steel 40XGT : 0·4% C, 0·36 % Si, 0·79% Mn, 1·73% Cr, 0·052 Ti, 0·0252% S, 0·0132% P

Steel 40CGM : 0·44% C, 1·71% Si, 1·24% Mn, 0·17% Cr, 0·33% Mo, 0·028% S, 0·039% P

Both steels were prepared in a 30 ton induction furnace. The test specimens were taken from 120 mm. rounds which had been rolled from 5 ton ingots.

The optimum quenching temperature was determined by both the thermal and the micrographic methods. For this purpose test bars of 50 mm. diameter were quenched in oil from 800, 820, 850, 880, and 900 deg. C., respectively. These specimens exhibited the following Brinell values, based upon a 10 mm. dia. ball loaded with 3000 kg . :

	Hardening Temperature, deg. C.				
	800	820	850	880	900
Steel 40 *XGT*					
Diameter of Brinell indentation ..	2·8	2·65	2·65	2·60	2·60
Steel 40 *CGM*					
Diameter of Brinell indentation ..	2·75	2·70	2·65	2·60	2·60

From these data it is seen that both steels show rising hardness values with increased temperature of quench, maximum hardness being reached at 880 deg. C. The chrome-manganese-titanium steel 40XGT was found to have a somewhat coarser grain than the silicon-manganese-molybdenum material 40CGM.

Test bars of 40, 60, 80, and 100 mm. diameter with a length of 1 = 2·5 dia. were machined from the rolled material. After quenching from 880 to 890 deg. C. in oil the test pieces were tested to destruction in an Amsler machine. All test pieces of both steels were found to be fully hardened in depth the hardness versus depth characteristics being charted in Fig. 1.

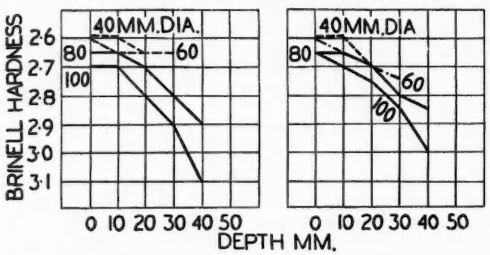

Fig. 1. **Hardness *versus* depth characteristics. Steels 40 XGT and 40CGM quenched in oil from 880-890 deg. C.**

Referring to these graphs it will be seen that the characteristics of the two steels are substantially similar. In the pieces of 40 and 60 mm. diameter full core hardness is obtained, while in the case of the larger diameters the presence of troosto-martensitic and troosto-sorbitic structure prevails at the centre of the piece, which results in a considerable decrease in hardness.

The mechanical properties of the two steels were ascertained by the tensile testing of bars of 5 mm. diameter and 30 mm. length and by the Charpy impact test. The results of these tests are charted in Fig. 2. With low tempering temperatures the chrome-manganese-titanium steel 40XGT possesses a high tensile strength and low impact strength. With a tempering temperature of 250 deg. C. this steel has an ultimate tensile strength of 197 kg. per sq. mm., a yield point of 177 kg. per sq. mm., an elongation of 9·7 per cent, and a reduction in area of 44 per cent. impact strength being registered at 2·69 kg. per sq. cm. and hardness being 514 Brinell. In view of these properties, a tempering temperature of 200–250 deg. C. should be adopted in cases where this material is to be subject to high static tensile load, and where dynamic loading is absent. Medium tempering should be avoided, as the impact strength of this steel after a 350 deg. C. temper is only 0·8 kg. per sq. cm. However, when tempered at 550–650 deg. C., this material is highly suitable for carrying dynamic loads, since, with a tempering temperature of 600 deg. C., the steel has an impact strength of 7·8 kg. per sq. cm., with an ultimate tensile strength of 105 kg. per sq. mm., and a reduction in area of 58 per cent. Compared to this material, the silicon-manganese-molybdenum steel 40CGM possesses considerably superior properties.

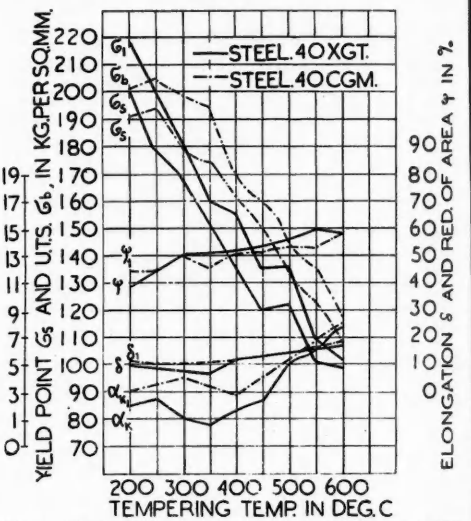

Fig. 2. **Mechanical properties of steels 40 XGT and 40 CGM as functions of the tempering temperature.**

With a tempering temperature of 250 deg. C. steel 40CGM exhibits an ultimate tensile strength of 203 kg. per sq. mm., a yield point of 190 kg. per sq. mm., an elongation of 10 per cent, a reduction of area of 45 per cent, and an impact strength of 3·8 kg. per sq. cm.; while its hardness is 514 Brinell. Within the range of tempering temperatures of 300 to 400 deg. C., the impact strength of the material is diminished, but far less than in the case of steel 40XGT. When tempered at 600 deg. C. steel 40CGM displays an ultimate tensile strength of 117 kg. per sq. mm., with a reduction of area of 58 per cent and an impact strength of 9 kg. per sq. cm. If tempered at high temperature, steel 40CGM is therefore comparable both with chrome-nickel steel and with chrome-nickel-molybdenum steel. The two steels 40CGM and 40XGT are considered a highly suitable material for engine shafts. Forging should be carried out at 1180–500 deg. C. The forging properties are substantially identical with those of chrome-nickel steels. After forging, pieces made of steel 40XGT should be normalised, while forgings of steel 40CGM should be slowly cooled to 550 deg. C.

INCREASING CIRCULAR GRINDING OUTPUT BY THE USE OF AUTOMATIC GAUGES AND CONTROL DEVICES.

By F. SCHAEFER. (From *Werkstattstechnik/Der Betrieb*, Vol. 38/23, 1944, pp. 187–190.)

IN grinding, more than in any other production method, efficiency is dependent on conditions which are difficult to control in normal workshop practice. Automatic gauges and control devices, however, afford special advantages in grinding, especially in modern mass production with its high demands on efficiency and accuracy.

PRELIMINARIES FOR CORRECT MEASUREMENT IN GRINDING.

If the grinding machine is in perfect condition and properly adjusted with the correct grinding wheel, then the dimensions of the work piece produced with it are, under ordinary conditions of circular grinding, dependent upon (*a*) the accuracy of the feed mechanism and the stops limiting the feed movement, (*b*) the wear of the wheel and its grinding capacity (this again depends on the frequency with which it is trued and the type of truing tool), (*c*) the composition of the coolant, (*d*) the bending strength of the work piece (elastic work pieces deflect under the grinding pressure and spring back slowly), and lastly (*e*) the experience and craftsmanship of the operator. All these influences on grinding efficiency vary continuously and they cannot, therefore, be expressed in figures.

A good operator will recognise the effects of vibration in a work piece and will try to minimise them. The greater the grinding accuracy has to be, the more frequently will the grinder have to interrupt the work to obtain it. When using fixed gauges, a work piece often has to be measured from four to six times and reground until the required dimension has been obtained. The operation is facilitated, however, if gauges are used which indicate the size of the work piece during grinding. Grinding, however, is not automatically interrupted by these gauges when the required final dimension is reached, so that no guarantee of uniformity can be made, as this, after all, depends on the skill and alertness of the grinder.

If the wheel feed is interrupted, as is usual, by a stop as soon as the wheel has reached the dimensions corresponding to the grinding tolerance of the work piece, it ceases sparking if the wheel is not further adjusted. When completely stopped—which, of course, is not possible in practice with elastic work-pieces on account of the great loss in time—it would remain larger than the dimension required by the amount of wheel wear during grinding. The experienced grinder balances the wheel wear by adjusting the stop of the feed mechanism from time to time. Size and frequency of the adjustment are purely a matter of experience, and cannot be calculated in advance and have to be considered as lost time.

To the inaccuracy due to wheel wear must be added variations in the feed mechanism, and the rapid movements of the table. As the mechanism consists of moving parts, it is never free from back-lash, and consequently is not absolutely correct. On a good circular grinding machine the tolerance in the feed movement, when limited by a fixed stop, will be about 0·005 mm. (0·0002 in.). This, however, is not sufficient for the grinding of parts with diameter tolerances less than 0·01 mm. (0·0004 in.). The grinder is thus compelled to obtain the required accuracy by changing both the position of the wheel and the duration of "sparking out" by frequent measuring. If he is unable to do so, for instance through lack of experience, the final dimensions will vary and there will be numerous rejects or readjustments to be made owing to the diameters of the ground portions being either too small or too large.

The more elastic the work pieces, the more they deflect under the wheel pressure, and the more difficult it is to balance for deflection and to obtain the required dimensions within a reasonable period of time. Although short work pieces rarely require a back rest to compensate for bending, it is frequently the only means of counteracting the deflection of longer work pieces. Experienced grinders even use the method of "back rest grinding" towards the end of the grinding process: the approach of the work piece towards the wheel can be effected by back bending the work piece under pressure by means of a back rest and not, as is customary, by feeding the wheel by means of the feeding mechanism of the machine. Therefore, however much the deflection influences the grinding, the result ultimately depends on the skill of the grinder.

ADVANTAGES OF AUTOMATIC CONTROL.

The above-mentioned factors can only be eliminated by appliances controlling the machine by the actual dimensions of the work-piece. The feelers of such appliances gauge the work-piece during the grinding operation and transfer the result to a dial, the hand of which usually operates two contacts which control the grinding operations. Table I gives the characteristics of a control device which has proved efficient during long continued use.

TABLE I.—TECHNICAL DATA ON AUTOMATIC MEASURING AND CONTROL DEVICES.

Range of diameters	$\frac{1}{8}$ to $1\frac{1}{8}$ in.
Measuring range	0·04 in.
Maximum grinding allowance	0·04 in.
Range of readings	0 to 0·003 in.
Interval between graduations	0·0002 in.
Measuring force	120 gr. (8$\frac{1}{2}$ oz.).
Stopping accuracy:—	
Grinding turned parts	0·00012 to 0·00016 in.
Grinding rough-ground parts	0·00008 to 0·00012 in.
Range of control of sparking-out	0 to 0·003 in.
Scale value of contact adjustment	0·00004 in.
Range of contact adjustment	± 0·0004 in.
Voltage of A.C. current used	220 volts.
Oil pressure	114 lb./sq. in.
Setting times:—	
First setting	15 min.
Adjustment for diameter	8 min.
Weight of measuring head (to be balanced by spring)	3·3 lb.
Shape of feelers for materials of strength	> 31·5 tons/sq. in. roller shape < 31·5 tons/sq. in. flat.
Width of feeler	0·235 in.
Displacement of measuring head by fluid piston	1·57 in.

In the following sections, only the influence of such devices on the grinding economy will be discussed, taking accuracy and efficiency as the criteria.

ACCURACY OF GRINDING.

Contrary to normal practice, grinding with an automatic gauging and controlling device is carried out without an end stop. The in-feed operates until the required dimension is obtained, whereupon the feed movement is automatically reversed by means of a contact. Up to this point the wheel is fed without taking account either of wheel wear, of the deflection of the work piece, of the flexibility of the feeding mechanism due to stresses or of the blunting of the wheel. The dimensional accuracy of the part to be ground is, therefore, determined only by the gauging device, which must operate absolutely reliably and accurately (Fig. 1).

Abstract by courtesy of Diamond Research Department, 32/34, Holborn Viaduct, London, E.C.1.

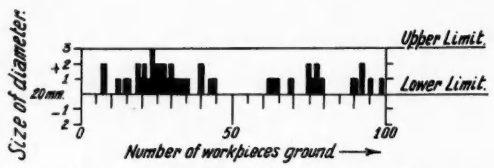

Fig. 1. **Accuracy of stopping of automatic measuring and control device.**
Results of tests on components (Fig. 4). Permissible limit 120 micro-in.; 59 per cent of the work pieces show the accurate dimension, 86 per cent a limit of less than 40 micro-in., 99 per cent smaller than 80 micro-in. None was in excess of the permissible limit.

The fixing of an optimum amount of final sparking-out has a considerable effect on the accuracy of parts with small tolerances. The " amount of final sparking-out " is defined as the thickness of the chip which has to be ground off, after stopping the grinding wheel feed, to obtain the final dimensions of the work-piece. It depends on the elasticity of the work-piece, the tolerance allowed for the diameter to be ground, the admissible eccentricity tolerance, the requisite surface quality of the work-piece, and on the working condition of the grinding wheel. It is not possible to vary the amount of final sparking-out when grinding against a stop; in this case the final sparking-out can only be arrived at by keeping the wheel in contact with the stop for a longer or shorter period. Frequent gauging and an experienced operator are, therefore, necessary for obtaining a comparatively uniform amount of sparking-out.* On the other hand, when grinding with an automatic sizing gauge, the amount of final sparking-out can be adjusted right away on the first work piece between limits of 0 to 75 microns (0 to 0·003 in.). In this way, adverse conditions during grinding do not affect the measurement of the work piece, but only lengthen the time of final sparking-out.

When grinding with an automatic sizing gauge, the wheel is fed—even during the final sparking-out—by very small increments, which is contrary to normal grinding procedure. It is, therefore, possible to subdivide the in-feed into " grinding feed " and " fine feed for final sparking-out " (Fig. 2). The speed of the

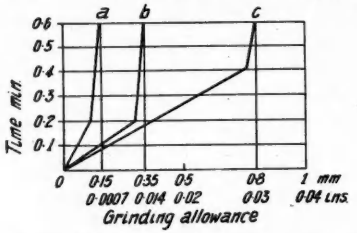

Fig. 2. **Course of feed in circular grinding with automatic measuring and gauging device.**
(*a*) Mandrel for balancing according to Fig. 3; short grinding time, long sparking-out time. (*b*) Valve according to Fig. 5; shorter sparking-out time compared with (*a*). (*c*) Shaft with diametral tolerance of 0·0008 in., long grinding time, short sparking-out time.

in-feed during final sparking-out can be adjusted so that in any event, a perfectly round surface free from grinding marks can be obtained. Correct adjustment of the in-feed during final sparking-out is of considerable importance for a satisfactory result, and sensitive work-pieces with very small tolerances for roundness, frequently require sparking-out times exceeding those for actual grinding.

The amount of the in-feed during " grinding " and " sparking-out " is not only determined by the degree of accuracy in grinding and the high surface finish to be obtained, but also by the required grinding efficiency. In any case, as the amount and the speed of sparking-out can be adjusted independently of each other, the optimum conditions of feed can be applied.

GRINDING EFFICIENCY.

Comparing grinding when using a stop, with grinding with the aid of an automatic sizing gauge, it is seen that not only the accuracy but also the efficiency of grinding is improved with the latter method. (Table II.)

The " main " time can usually be shortened by working with the maximum permissible feed. The accuracy in changing from grinding to sparking-out will, in fact, induce the grinder to use the greatest possible in-feed. Since, as already mentioned, the wheel has to be fed very slowly during the final sparking-out, it takes a long time and this must be reduced to a minimum.

The following example shows how grinding efficiency was reduced through an inaccurately adjusted final sparking-out. In finishing the shaft ends on the balancing mandrel in No. 1 (Table III) an in-feed of about 0·15 mm. (0·006 in.) in diameter is necessary. Taking into account the elasticity of the work-piece and the required roundness of the part to be ground, the final sparking-out has to be adjusted to about 30 micron. (0·0012 in.). If, as is quite possible when grinding with an end stop, it is adjusted only 10 microns (0·0004 in.) larger, the time for final sparking-out will be increased by one-third. The final sparking then takes, for example, 0·47 min. instead of 0·35 min.

These hitherto unavoidable differences in sparking-out time, which reduce grinding efficiency, may be eliminated by automatic sizing. In the example given above, the in-feed will be retarded to the much slower in-feed for sparking-out (which itself can be regulated), when there is only an allowance of exactly 30 microns (0·0012 in.) left for final sparking-out.

This reliability of control enables the grinder to carry out various regular minor activities during grinding, such as the changing of carriers, cleaning of centre holes, etc., with greater smoothness than when grinding with end stops, since he has no fear of the component in the machine becoming scrap in the meantime. This, too, may indirectly have a beneficial effect on the grinding efficiency. This advantage will become more apparent when parts have to be ground very accurately, the production of which would otherwise require the fullest attention of the grinder, resulting in quick fatigue. His personal efficiency will remain nearly uniform throughout the whole of his working time, and the decrease in output towards the end of his shift will be correspondingly small.

The " supplementary time " can be shortened by means of automatic sizing gauges even more than the " main time." Above all, the time necessary for the repeated measurement of the diameter during production can be eliminated, since the devices measure continuously during the whole of the grinding operations. The frequent backward and forward movement of the wheel, and the insertion of gauges for intermediate measuring are thus eliminated. The feeler of the automatic gauge is set together with the starting of the machine operation, and no special time for this operation is needed. The grinder can utilise the whole time during both actual grinding and final sparking-out for preparing the next work-piece.

As " supplementary time " only that for firstly changing the work-piece (and this is considerably

* The time fixed for grinding and final sparking-out on a semi-automatic circular grinding machine remains constant after a certain amount of adjustment, and is dependent on the kind of work. If, however, small tolerances for the diameter and the shortest possible working times are required, the resiliency of the work piece, the wear and variation in cutting capacity of the wheel, and the inaccuracy of the feed mechanism will all have their effect, and will frequently result in diameter sizes outside the limits of tolerance.

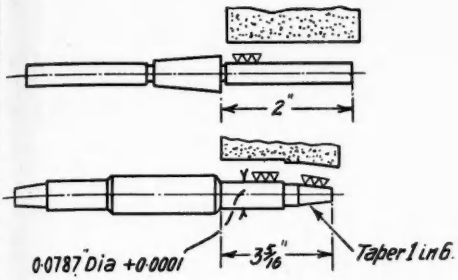

Fig. 3. **Mandrel for components to be balanced.**
Both shaft ends and the cone in the centre must be absolutely central. The component is rough ground. The shaft end must be absolutely cylindrical.

Fig. 4. **Spindle.**
The seat of 0·79–0·00012 in. had, hitherto, to be lapped after grinding, due to the small allowance. When using automatic measuring and control devices this has to be obtained by grinding alone. Time for lapping saved, therefore big increase in capacity.

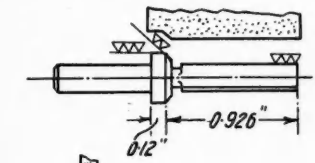

Fig. 5. **Valve shaft.**
Cone and grooved cylinder of 0·236 in. diameter must be absolutely central. The three grooves in the cylindrical portion prevent a touching of the part. The automatic measuring and control device is therefore used for the diameter of 0·315 in.; this is ground with cone and cylinder in one operation.

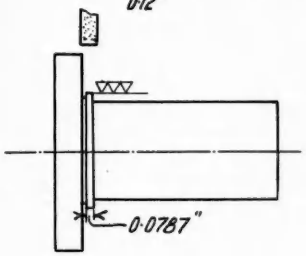

Fig. 6. **Bolt with head.**
The big diameter is ground by in-feed. The measuring head of the automatic measuring and control device is equipped with a special anvil, so that the cylinder of small width is touched with safety; savings mainly through avoiding of measuring times and reduced setting time.

TABLE II.—Times Necessary for the Grinding of a Bolt of 0·315 in. diam. (Fig. 3). Other Conditions are considered to be Identical

	Grinding with Automatic Gauge		Grinding with Fixed Stops							
			Control Snap Gauge		Work Piece checked with Standard Gauge		Setting Gauge		Indicating Instrument on Machine	
	min.	%	min.	%	min.	%	min.	%	min.	%
Main time t_h ..	0·55	100	1·6	290	0·95	173	0·95	173	0·80	145
Auxiliary time, t_n	0·2	100	0·88	440	0·69	345	0·63	315	0·50	250
Basic time, t_g ..	0·75	100	2·48	330	1·64	219	1·58	210	1·30	173

TABLE III.—Examples of Grinding with the Use of Automatic Measuring and Control Devices.

Work-Piece	Operation	Grinding Allowance	Limit	Batch Size	Grinding Wheel	Accuracy obtained			Main Time	Auxiliary Time	Basic Time		Increase in Capacity
					Dia. in × width	Roundness	Cylindricity	Maintain. diam.			With Autom. measuring	Without measuring	
		in. dia.	in. dia.	No.	in.	micro-in.	micro-in.	micro-in.	min.	min.	min.	min.	%
Mandrel (Fig. 3).	Finishing shaft 0·315 in. diam.	0·006	0·0002	200	24 × 2	40	40	160	0·55	0·20	0·75	1·3	74
Spindle (Fig. 4).	Finishing cone and shaft ends with form wheel	0·006	0·00012	200	24 × 3·5	40	40	80	0·65	0·25	0·9	2·0	123
Valve shaft (Fig. 5).	Finishing cone and diam. of 0·236 and 0·355 in. with form wheel.	0·014	0·0002	250	24 × 1¼	40	40	120	0·5	0·2	0·7	1·2	72
Bolt (Fig. 6).	Finishing small cylinder of 1·57–0·0002 in.	0·016	0·0002	100	24 × ⅜	80	—	120	0·4	0·2	0·6	1·8	200

shortened by the withdrawal of the gauge by 40 mm. ($1\frac{9}{16}$ in.)), and secondly, the time needed for starting the in-feed movement, have to be considered. The truing time, as usual, has to be considered in proportion to each work-piece.

POSSIBILITIES OF APPLICATION.

The examples in Table III show the advantages of grinding with an automatic sizing gauge. Example 3 demonstrates how a part that, at first sight, appears unsuitable for grinding with an automatic sizing gauge can be produced by this method after a second diameter has been provided.

The use of the automatic sizing gauge on circular grinding machines for series and mass production can be justified on the saving in time alone. If the small tolerance of the work piece (less than 0·005 mm. (0·0002 in.)) does not directly require grinding with such devices, the safety of the grinding process would recommend its application. This applies in particular to work pieces which are already charged with considerable costs by previous processing, and the scrapping of which would mean a heavy loss.

The increased safety in the grinding process has the further advantage that machines with automatic sizing gauges can be operated by less skilled personnel since their work is limited only to the changing of the work-piece and the starting of the machine.

When deciding whether the devices could be used for grinding of components with larger diameter tolerances, or even for rough grinding, it is an important consideration, the fact that they permit multi-machine operation. It is especially beneficial in longitudinal grinding (with its longer "main" times, for which automatic sizing gauges are particularly useful.

Automatic sizing gauges can be used on new grinding machines or machines already in use. Only machines with hydraulic feed movement, automatic in-feed of the wheel, and rapid movement of the table, are suitable for adaptation, however. The in-feeding of the wheel has to be capable of sensitive adjustment so that the optimum in-feed can be selected.

SUMMARY.

Grinding on circular grinders with automatic sizing gauge permits very accurate and uniform dimensions to be obtained with a considerable saving in time. These devices also increase the safety of the grinding process and reduce the number of rejects. Such devices can be fitted on suitable machines already in use, thus considerably increasing the efficiency. Grinding machines fitted with such devices can be operated by trainees, and under favourable conditions by girls, in spite of high demands for efficiency and accuracy. With sufficiently long "main" times, multi-machine operation is possible.

Automatic sizing gauges have shown their value for diameters up to 60 mm. ($1\frac{9}{16}$ in.) in continuous production; devices for diameters up to 125 mm. (5 in.) are in preparation, whilst similar devices may prove useful for internal grinding.

GAS-WAVE ANALOGIES IN OPEN-CHANNEL FLOW.

(From *University of Iowa Bulletin* 27, No. 400, pp. 248-266. Proceedings of Second Hydraulic Conference, June, 1942).

NUMEROUS hydraulic structures have been erected in recent years, in which rather high velocities of flow were employed for the efficient handling of large discharges in channels with a free surface. In many instances the first design of such structures was approached with such concepts of flow as had been formed through contact with flow phenomena in natural streams and in artificial channels of moderate slopes. Consequently, the performance of these high-velocity structures very often did not come up to expectations. Sometimes the chief reasons were surprising standing-wave patterns, which affected the flow in curved sections of steep flood channels, in channel contractions and expansions, in log chutes, storm-drain intakes, and other types of hydraulic structures. The elimination of the undesirable features of these structures was often achieved by the experimental method, applied in most cases rather hurriedly and resulting in empirical corrections without general benefit to the knowledge of high-velocity flow in open channels. Some research projects in this field, however, were carried out in such a way as to permit quite a detailed analysis of the nature of this so-called "shooting" or "rapid" flow in certain cases. It is the purpose of this paper to summarize the general results of these theoretical and experimental investigations and to bring them to wider attention among hydraulic engineers as useful tools in the design of high-velocity structures.

Since much of the progress in the analysis of high-velocity flow of water was due to the existence of extensively developed solutions in the supersonic flow of gases, it is only fitting to start out with a brief summary of this analogy.

That physical relationships must exist between high-velocity gas and liquid flow is immediately recognized from pictures, showing, for example, the pressure-wave pattern created by a bullet in air and the wave disturbances of a similarly shaped bridge pier in water. The difference in the two cases is only apparent from the fact that the shock waves originating at the sharp tip of the bullet are visible as thin lines typical of shock waves in gases, while shock waves in water, better known as standing wave fronts or hydraulic jumps, extend over a larger width.

The basic features of the analogy are obtained from the continuity, energy, and momentum relationships as commonly applied in hydrodynamics. The following assumptions are made: the flow in either medium is considered two-dimensional in the xy plane, the flow is steady and frictionless, and the gas-flow is considered adiabatic—i.e., no heat is added to or taken from the fluid. The energy equation then reads:

$$h + \frac{V^2}{2g} = H_o = \text{const.} \quad .. \quad (1a)$$

wherein V is the velocity of flow at any point and h or H_o represents enthalpy or total heat content in foot pounds per pound. The difference in enthalpy $(H_o - h)$ can be expressed in accordance with the assumption of adiabatic conditions in terms of H_o by the following expression:

$$\frac{V^2}{2g\,H_o} = \frac{H_o - h}{H_o} = \frac{T_o - T}{T_o} \quad .. \quad (1b)$$

with T representing total absolute temperature. Considering the flow of water with a free surface on a horizontal xy plane and assuming hydrostatic pressure distribution and no friction losses, Bernoulli's theorem is written in exactly the same form as equations (1a) and (1b). The term H_o becomes the total head H_o with respect to the bottom, commonly known as "specific energy"; h is simply depth of flow.

Since the enthalpy for gases under the conditions stated depends only on certain constants and the temperature T, the conclusion from equation (1b) is that

$$\left[\frac{h}{H_o}\right]_{\text{water}} = \left[\frac{T}{T_o}\right]_{\text{gas}}$$

The continuity equations are written for gas and for water in the two-dimensional case as follows:

For gas : $$\frac{\partial (\rho V_x)}{\partial x} + \frac{\partial (\rho V_y)}{\partial y} = 0 \qquad (2)$$

For water : $$\frac{\partial (h V_x)}{\partial x} + \frac{\partial (h V_y)}{\partial y} = 0 \qquad (3)$$

and result in the analogy stated in equation (4) :

$$\left(\frac{\rho}{\rho_o}\right)_{gas} = \left(\frac{T}{T_o}\right)^{\frac{1}{K-1}} = \left(\frac{h}{H_o}\right)_{water} \quad .. \qquad (4)$$

The ratio of the densities, $\frac{\rho}{\rho_o}$, is found to correspond to the ratio of the water depths. Since the latter is also analogous to the ratio of temperatures in gas flow, as the result of equation (1b), a perfect correspondence of the related quantities is only possible for a hypothetical gas with $k = \frac{c_p}{c_v} = 2$. However, many flow phenomena do not depend very strongly on the value of k, so that actual gas flow (for air, $k = 1{\cdot}4$) show satisfactory agreement with the corresponding flow of water in numerous problems.

The pressure p in gas flow is not proportional to the depth h as one might be inclined to expect. In accordance with the thermodynamic principle $\frac{p}{p_o} = \left(\frac{\rho}{\rho_o}\right)^K$, and using $k = 2$ as derived before, the comparison gives

$$\left(\frac{p}{p_o}\right)_{gas} = \left(\frac{\rho}{\rho_o}\right)^K_{gas} = \left(\frac{h}{H_o}\right)^2_{water} \quad .. \quad .. \qquad (5)$$

This latter analogy may be given a physical meaning, however, by relating total hydrostatic pressure $P = \frac{wh^2}{2}$ to the pressure intensity in gas flow. This results in

$$\left(\frac{p}{p_o}\right)_{gas} = \left(\frac{P}{P_o}\right)_{water}$$

It remains to relate the velocity of sound or of pressure disturbances in gases to the velocity of equivalent disturbances in water flowing in a horizontal channel (the channel may also be inclined so as to compensate for friction forces by a gravity component). The velocity of sound in gases is given by $a = \sqrt{\frac{kp}{\rho}}$, and the ratio of a to the velocity of sound a_o for an initial state H_o would be given by

$$\frac{a}{a_o} = \sqrt{\frac{p}{p_o} \cdot \frac{\rho_o}{\rho}} \quad .. \quad .. \qquad (6)$$

Using the analogies found so far from equations (4) and (5), the equivalent ratio for water flow is $\sqrt{\frac{h}{H_o}}$ or, written in the final form,

$$\frac{a}{a_o} = \sqrt{\frac{gh}{g\,H_o.}} \quad .. \quad .. \qquad (7)$$

The quantity $\sqrt{gh}$ is recognised as the speed of propagation of small waves or surges in shallow water, which is also often called the "celerity" (C). Therefore, the quantity analogous to the velocity of sound in gases is the wave velocity in open channels, provided the height of the wave front remains small as compared to the depth of flow.

In gas dynamics as well as in hydraulics, use is made of the ratio of the velocity of flow to the velocity of a pressure disturbance to indicate the state and character of flow. The ratio of the velocity of gas flow to the velocity of sound, $\frac{V}{a}$, is commonly known as the Mach number, which has its equivalent in hydraulics in the Froude number $\frac{V}{\sqrt{gh}} = \frac{V}{C}$. Equal values of these numbers therefore indicate comparable conditions of flow.

The hydraulic engineer encounters quite frequently in his practical problems a sudden change in water-surface elevation, which is known as a standing wave ; if it is at right angles to the direction of flow it becomes the familiar hydraulic jump. The latter has been thoroughly treated and its theory and experimental confirmation can easily be learned from most standard texts. The following treatment will take up the slanting hydraulic jump or the standing wave of the shock type ; the word "shock" is borrowed from the terminology in gas dynamics and indicates a rather sudden change of flow conditions.

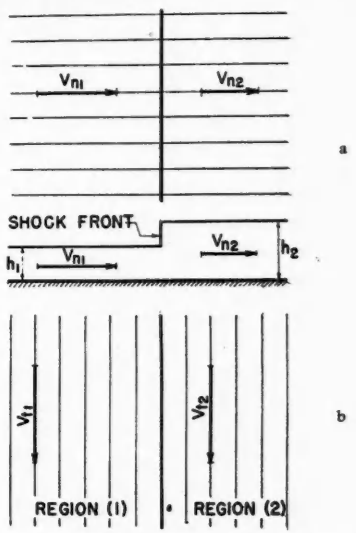

Fig. 1. Standing jump at right angles to flow.

Let Fig. 1a be the plan and elevation of such a standing jump at right angles to the flow and let the jump front be represented by a single line. The velocity of approach, for reasons apparent later, may be called V_{n1} and the exit velocity V_{n2} ; the corresponding depths are h_1 and h_2. The streamlines are normal to the jump front.

In Fig. (1b) below, a second field of flow is shown—or rather, two fields of flow—with streamlines parallel to the vertical line, indicating a change in depth from h_1 to h_2 but with velocities V_{t1} and V_{t2} equal and parallel to the front. Since there is no flow across the front, it may best be thought of as a definite boundary such as a thin plate separating the two streams.

In Fig. 2 the flows of (1a) and (1b) are superposed ; the definition of the original quantities should be well remembered. The velocities V_1 and V_2 obtained by this superposition are composed of components normal and parallel to the wave front, and the place of the boundary in Fig. 1b is now taken by the jump front separating the regions (1) and (2). The normal component V_{n1} by definition is also the velocity of the jump

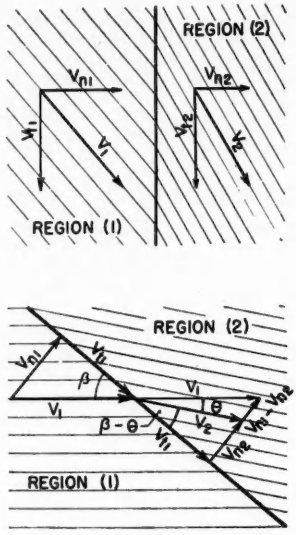

Fig. 2. **Flow of Fig. 1 superposed.**

or wave front, so that $\frac{V_{n1}}{V_1}$ is the sine of the angle β, properly termed the wave angle. The fact that V_{n1} changes to V_{n2} for flow across the jump line, while V_{t1} and V_{t2} remain the same, means in effect, a change in direction by an angle Θ for the velocity of flow from V_1 to V_2.

The application of continuity and momentum relationships, combined with the geometry of the velocity vectors, results in equations (8) to (14). Thus,

$$h_1 V_{n1} = h_2 V_{n2} \quad .. \quad .. \quad (8a)$$

$$h_1 V_1 \sin \beta_1 = h_2 V_2 \sin (\beta_1 - \Theta) \quad .. \quad (8b)$$

$$\frac{h_2^2 - h_1^2}{2 h_1} = \frac{V_{n1}(V_{n1} - V_{n2})}{g} \quad .. \quad (9)$$

From equation (9), with the aid of equation (8a) the jump celerity V_{n1} can be expressed solely in terms of h_1 and h_2 :

$$V_{n1} = V_1 \sin \beta_1 = C = \sqrt{g h_1 \frac{1}{2}\frac{h_2}{h_1}\left(1 + \frac{h_2}{h_1}\right)} \quad .. \quad .. \quad (10)$$

The celerity becomes equal to the critical velocity only if the ratio $\frac{h_2}{h_1}$ approaches unity. Replacing $\frac{V_1}{\sqrt{g h_1}}$ by the familiar Froude number F_1, equation (10) may also be written as

$$\sin \beta_1 = \frac{1}{F_1}\sqrt{\frac{1}{2}\frac{h_1}{h_2}\left(1 + \frac{h_2}{h_1}\right)} \quad .. \quad .. \quad (11)$$

For a given relative height of jump the angle β_1 will depend only on the value of F_1 — i.e., on the depth and velocity of approach. The minimum value of sin β for any given F can only be sin $\beta = \frac{1}{F}$, since h_2 would have to become smaller than h_1 to reduce sin β below this value. A hydraulic jump is always accompanied by a certain energy loss ΔH, however small, which is given by equation (12) in terms of initial depth h_1 :

$$\frac{\Delta H}{h_1} = \frac{\left(\frac{h_2}{h_1} - 1\right)^3}{4\frac{h_2}{h_1}} \quad .. \quad .. \quad .. \quad (12)$$

From equation (12) it is easily seen that for all ratios $\frac{h_2}{h_1}$ smaller than 2, the energy loss is only a small fraction of the initial depth h_1, which in itself is small compared to the total head or energy in most supercritical flows of a practical nature. We may therefore treat shock waves even as high as the initial depths as jumps without energy dissipation.

Equation (11) should be discussed further to bring out two particular points. First, the maximum value of β cannot exceed 90 deg. ; if it approaches that value, the jump will detach itself from the source of disturbance and travel upstream, the limiting values of F and $\frac{h_2}{h_1}$ easily being found from the equation for this condition. The second point to note is the fact that for the slanting jump there is no restriction placed on the values of h_2 with respect to V_2. Depending upon the relative magnitudes of V_t and V_{n2}, $\sqrt{g h_2}$ may be smaller or larger than V_2—i.e., the flow for a slanting jump may be either tranquil or rapid, streaming or shooting. The critical flow, where $V_2 = \sqrt{g h_2}$, can be obtained from the equations by substituting this condition.

Missing so far is an expression for the angle of deflection Θ. The geometry of the vector diagram and equation (8b) result in

$$\frac{h_1}{h_2}\tan \beta = \tan (\beta - \Theta)$$

so that finally

$$\tan \Theta = \frac{\left(1 - \frac{h_1}{h_2}\right)\tan \beta}{1 + \frac{h_1}{h_2}\tan^2 \beta} \quad .. \quad .. \quad (13)$$

This last equation may be simplified considerably if it is applied to values of $\frac{h_1}{h_2}$ and β occurring in practice. If $\frac{h_1}{h_2}$ is assumed to vary only between $\frac{2}{3}$ and $\frac{1}{3}$ and if β ranges between values of 10 deg. and 35 deg., only a small error results from replacing

$$\frac{\tan \beta}{1 + (h_1/h_2)\tan^2 \beta}$$

simply by sin β. Equation (14) is the result :

$$\tan \Theta = \left(1 - \frac{h_1}{h_2}\right)\sin \beta \quad .. \quad .. \quad (14)$$

This equation can be combined with equation (11) to give the deflection Θ in terms of F and $\frac{h_1}{h_2}$ alone.

WAVE FRONTS OF SMALL HEIGHT— ASSUMPTION OF CONSTANT ENERGY.

All previous equations are valid for the assumptions made, regardless of the energy dissipation, ΔH. If for the present the case of zero energy dissipation is considered, these equations can be greatly simplified. Zero energy dissipation requires a ratio $\frac{h_2}{h_1}$ approaching unity,

which obviously is only possible for a very small deflection angle $d\Theta$, while sin β approaches the limiting value $\frac{1}{F}$. Equation (13) then results in the differential expression

$$d\Theta = \frac{d\,h}{\frac{V^2}{g}\tan\beta} \qquad \ldots \quad \ldots \quad \ldots \quad (15)$$

The small angular change $d\Theta$ may be negative or positive, causing a decrease or increase of the depth along a disturbance line crossing the flow at an angle $\beta = \sin^{-1}\left(\frac{1}{F}\right)$. Such disturbance lines may be drawn

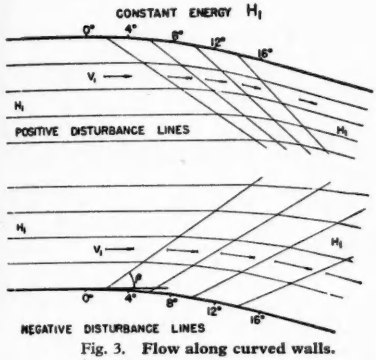

Fig. 3. **Flow along curved walls.**

along a curved wall, as shown in Fig. 3, approximating the curvature by a series of short tangents or chords for definite angles—say $d\Theta = 2$ deg. or even 4 deg. Fig. 3 shows these disturbance fronts and their effect on the stream lines.

At this point, however, the attention of the practical engineer may be called to a graphical solution. The basis for the graphical method known as the "method of characteristics" in gas dynamics is given by equation (15). This equation can be transformed into a general relationship for a dimensionless velocity defined as

$\bar{v} = \frac{V}{\sqrt{2gh}}$, wherein the total head $H = h + \frac{V^2}{2g}$ in accordance with the former notation. Since then $h = H(1 - \bar{v}^2)$

and $\tan\beta = \frac{V_n}{V_t} = \frac{\sqrt{gh}}{\sqrt{V^2 - gh}}$,

equation (15) may be written as

$$\frac{1}{\bar{v}}\frac{d\bar{v}}{d\Theta} = \frac{\sqrt{1-\bar{v}^2}}{\sqrt{3\,\bar{v}^2 - 1}} \qquad \ldots \quad (16)$$

This is the equation of an epicycloid between the circles of radii $\bar{v} = \frac{1}{\sqrt{3}}$ and $\bar{v} = 1$, since for supercritical flow $\bar{v}$ has as limiting values $\bar{v}_{max} = 1 = \bar{v}\sqrt{2gH}$ and $\bar{v}_{min} = \sqrt{\frac{H}{3H}} = \frac{1}{\sqrt{3}}$ for critical flow. The curve or "characteristic" plotted for the above equation between these limits will give all possible values of $\bar{v}$ and Θ for shooting flow for the assumption of constant energy and for a wave velocity $V_n = \sqrt{gh}$. In agreement with these conditions the angular intervals $\Delta\Theta$ have to be small—say 2 deg. or 4 deg.

In Fig. 4 such characteristic curves are drawn at angular intervals of 4 deg. to correspond to angular changes of streamlines along curved walls or under wave fronts of equal influence. Curves are drawn upward and downward, giving positive and negative direction changes with respect to any initial direction. Moving outward along any curve will give increasing values of $\bar{v}$ corresponding to the crossing of negative wave fronts, and moving inward will result in decreasing values of $\bar{v}$ due to positive wave fronts. In order to obtain not only the changes of the velocities but also the directions of the wave fronts or boundaries along which these changes take place, it remains to construct an additional curve. This curve must have the property of giving the magnitudes and the directions of $\bar{v}_n$ and $\bar{v}_t$ for all possible values of $\bar{v}$ and can be shown to be an ellipse with the major axis $\bar{v}_{max} = 1$ and the minor axis $\bar{v}_{min} = \frac{1}{\sqrt{3}}$. The following development gives the equation for $\bar{v}_n$ and $\bar{v}_t$:

$$V_n^2 = gh = gH - \frac{V^2}{2}$$

$$V_t^2 = V^2 - V_n^2 = V^2 - gH + \frac{V^2}{2}$$

On eliminating V^2 from these equations, there is obtained the general equation

$$3\,V_n^2 + V_t^2 = 2\,gH$$

or

$$\frac{\bar{v}_n^2}{\frac{1}{3}} + \frac{\bar{v}_t^2}{1} \qquad \ldots \quad \ldots \quad \ldots \quad (17)$$

This ellipse, for purposes of graphical construction is best engraved on a piece of celluloid which can be rotated freely over the characteristics diagram. The two diagrams are shown separately in Fig. 4 only to avoid confusion. The example showing the principle of

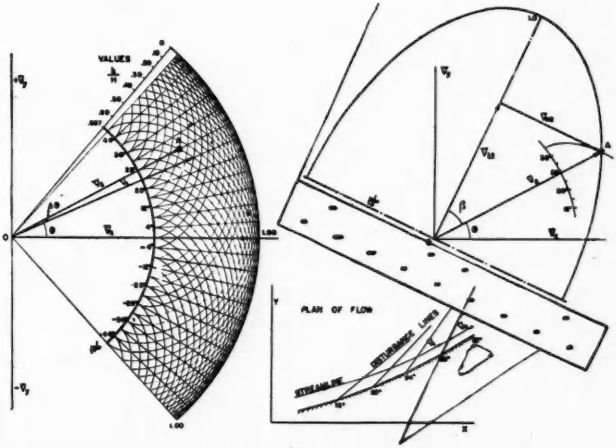

Fig. 4. **Characteristics diagram.**

application considers the flow along a wall curved toward the stream in the xy plane. For a given value of $\bar{V}_1$ at an angle θ_1 to the x axis the epicycloid is found in the characteristics diagram. A further change of angle $\Delta\theta = 4$ deg. along the wall will cause $\bar{V}_1$ to decrease to a value $\bar{V}_2$ along this epicycloid. The ellipse can then be rotated until it intersects this epicycloid at A. The direction of the major axis is the direction of $\bar{V}_t$ and therefore of the wave front separating zone (1) from zone (2) in the plan. The value of $\bar{V}_2$ determines the ratio $\frac{h_2}{H}$, which can be obtained on the diagram directly from the scale indicated.

It is possible to build up by this method a relatively complicated pattern of wave fronts of positive and negative sign, which in the end permits the construction of a contour map of the entire fluid surface.

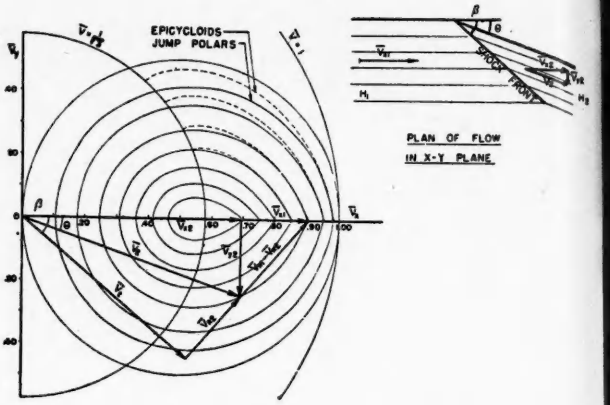

Fig. 6. **Polar diagram for slanting hydraulic jump.**

THE "METHOD OF SHOCK POLARS" FOR SUPERCRITICAL FLOW WITH HIGH WAVE FRONTS AND ENERGY DISSIPATION.

As explained in the preceding section, the effect of wall curvature may be concentrated over a short distance due to the convergence of the positive wave

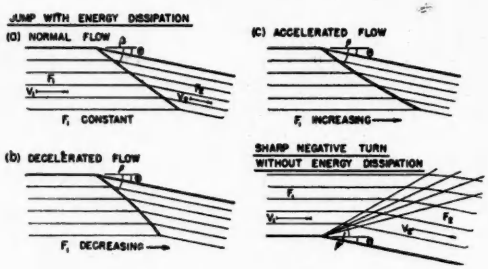

Fig. 5. **Flow past sharp corners.**

fronts, and a steep wave front or shock wave may be created. This would be equivalent to the effect of a sudden angular change along the wall, as shown in Fig. 5, with the wall turning toward the flow. A shock wave or jump with energy dissipation originates at any such sharp corner crossing the flow at an angle β, as given by equation (11). If, however, the wall turns away from the flow (Fig. 5) no shock-wave is created, since there can be no energy dissipation. The sudden drop can be imagined to disintegrate into a number of diverging wave fronts of small height.

The "method of shock polars" for supercritical flow is based on the fundamental relationships contained in equations (8) to (14), and takes into account the influence of energy dissipation and wave height. The graphical analogy to the epicycloids in the preceding chapter results in other characteristic curves, the so-called shock polars, which as before give the direction and magnitude of the velocity $\bar{V}_2$ for all possible deflection angles θ if the initial conditions $\bar{V}_1$ and h_1 are given. These curves are shown in Fig. 6. The portions of the curves lying within the limiting circles of radius $\bar{V} = 1$ and $\bar{V} = \frac{1}{\sqrt{3}}$ give very nearly the end condition $\bar{V}_2$ in the supercritical range of flow and the parts within the inner circle give the subcritical velocity $\bar{V}_2$. Within the latter are therefore located the values of $\bar{V}_2$ for $\theta = 0$ — i.e., for the normal hydraulic jump. The plotting of these curves is materially aided if the equations are transformed to contain the x and y components of $\bar{V}_2$ instead of $\bar{V}_{n2}$ and $\bar{V}_t$. The geometric relationships of equations (18) and (19) introduced into equations (8) and (9) together with the energy equation yield the following expressions for the "jump-polar" or "shock-polar curves":

$$\bar{V}_{n1}(\bar{V}_{n1} - \bar{V}_{n2}) = \bar{V}_{x1}(\bar{V}_{x1} - \bar{V}_{x2}) \quad .. \quad (18)$$

$$(\bar{V}_{n1} - \bar{V}_{n2})^2 = \bar{V}_y^2 + (\bar{V}_{x1} - \bar{V}_{x2})^2 \quad .. \quad (19)$$

$$\bar{V}_y^2 = \bar{V}_{x1}^2 \left(1 - \frac{\bar{V}_{x2}}{\bar{V}_{x1}}\right) \times \left[\frac{\bar{V}_{x2}}{\bar{V}_{x1}} - \frac{\sqrt{1 - \bar{V}_{x1}^2}}{\sqrt{1 - \bar{V}_{x1}^2 + 4\bar{V}_{x1}^2\left(1 - \frac{\bar{V}_{x2}}{\bar{V}_{x1}}\right)}}\right] \quad (20)$$

The bar over the velocity components again indicates a dimensionless ratio such as $\bar{V}_1 = \frac{V_1}{\sqrt{2gH_1}}$. For critical flow, obviously, $\bar{V}_{x1} = \bar{V}_{x2}$ and $\bar{V}_y = 0$. In using the diagram it must be remembered that in accordance with the above definition the velocities $\bar{V}_2$ represent percentages of $\sqrt{2gH_1}$. Since every jump is accompanied by a certain energy dissipation $(H_1 - H_2)$, every $\bar{V}_2$ has to be adjusted to the new lower state of energy H_2, before the diagram can be used again from a region (2) to a region (3). In other words, the quantity $\bar{V}_2$ is to be multiplied by $\sqrt{\frac{H_1}{H_2}}$, which is always larger than unity. The diagram is then oriented anew with the x axis in the direction of the corrected value of $\bar{V}_2 = \frac{V_2}{\sqrt{2gH_2}}$.